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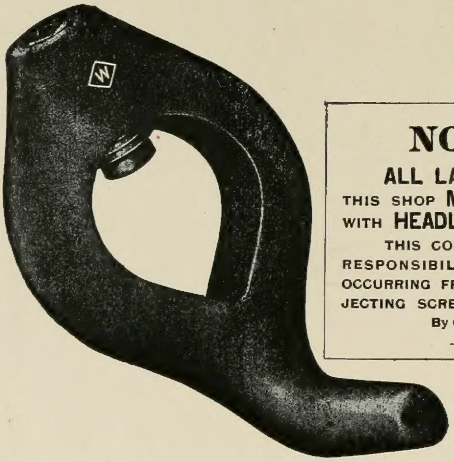

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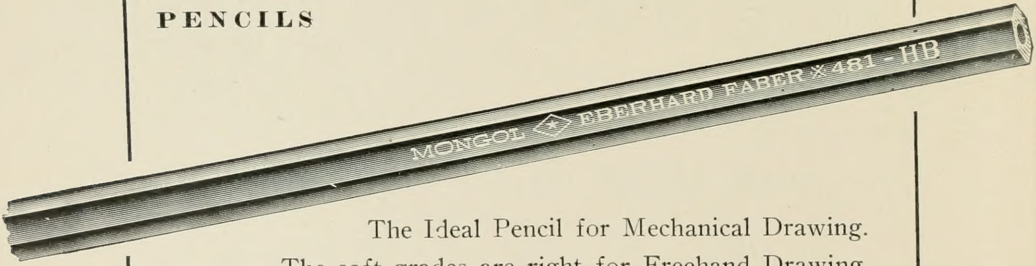

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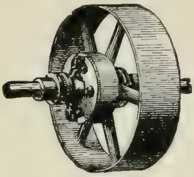

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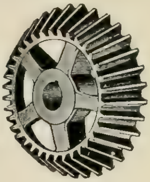

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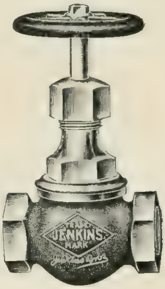

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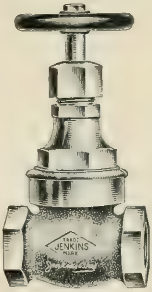

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Vol. XIII.

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SAMUEL SHELDON, M.A., Ph.D., Sc.D.

Fellow and Past President, American Institute of Electrical Engineers;
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Author of Dynamo-Electric Machinery (Eighth Edition);
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Electric Traction and Transmission Engineering;
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PROFESSOR SAMUEL SHELDON

AS A TOKEN OF ITS ADMIRATION FOR HIM IN WHOSE
THOUGHTS THE PROGRESS OF THE POLYTECHNIC
INSTITUTE IS EVER FOREMOST

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Vol. XIII. MAY 1, 1913.

EDITORIALS

By eternal laws
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The cycle of
Their destiny.

JOHANN WOLFGANG VON GOETHE.

FOREWORD.

To those who have contributed the support which makes possible this issue of the "Polytechnic Engineer" we are thankful beyond expression. But for the keen interest manifested by the faculty, the alumni, the undergraduates, and our friends, our work could never have been done.

The unbiased selection of material is the most difficult and painful duty imposed upon a board of editors. We regret that circumstance limits our publication and we trust that that may be understood by those whose articles have been rejected.

I take great pleasure in hereby formally thanking my associates for their efforts in behalf of the "Engineer" and for the able assistance they have rendered me. To Mr. Harry Young great credit is due for his enthusiastic participancy in the arduous tasks of editing, to Mr. Irving Hayward for the able manner in which he carried the business management to a successful end, to Mr. Willis Cole, who redrafted a majority of the drawings presented in this volume, and to Mr. Edward Reilly, who by his skillful and well-applied energy promoted the circulation of the issue.

It has been a source of no little comfort to realize that these men have been always willing to undertake whatever required doing, and to them alone is the success of this thirteenth volume of the "Engineer" to be attributed.

ACKNOWLEDGMENT.

The artistic appearance of our volume has been greatly enhanced by several prints which are published by the courtesy of certain prominent engineers and engineering concerns. We are grateful for the cuts accompanying the article entitled "The Pitot Tube," to Mr. Edward S. Cole of New York, Professor F. B. Sanborn of Tufts College, and for photographs presented by The Simplex Valve and Meter Company of Philadelphia, Pa. For the cuts illustrating the article "The Diffusion of Light by Mechanical Means" we are indebted to The Cooper Hewitt Electric Company, Hoboken, N. J.

ACKNOWLEDGMENT.

The editorial staff wishes to express its gratitude to Professor Samuel Tucker for his assistance in reading and revising portions of the manuscript submitted, and to Mr. George W. Oxley, retired Assistant Editor and Business Manager, for his helpful suggestions concerning this publication.

THE HISTORY OF BRIDGE BUILDING.

In his most fascinating article, Professor Hudson has traced the development of bridge construction from the earliest periods in the history of civilization.

When one has become accustomed to viewing the most remarkable engineering projects of the twentieth century, when one dwells continuously in the great "City of Cities," he cannot understand that there must have been a time when our own powers had their beginning.

It requires no unusual imagination to mentally visualize the lucid descriptions, as presented hereinafter, of Cæsar's Bridge, of the primitive rope structures which spanned the impassable gorges of the Andes, and of the various other feats of mediæval man which marked but the evolutionary stages of the wonders unfolded before us in our own day.

THESES

We have published within these covers the titles of the theses submitted in June, 1912, to the faculty of the Polytechnic Institute by the candidates for degrees from the several engineering and chemistry departments. It is hoped that these may be of interest to our readers, representing, as they do, the most matured and careful work accomplished by the undergraduate body.

THE PITOT TUBE.

Everyone has heard something regarding the Pitot tube as an hydraulic measurement apparatus, but the multiplicity of uses to which it may be put is probably not so familiar. Professor Hammond's dissertation is as complete as it is interesting, and furnishes in a concise, logical form all of the facts essential to a thorough comprehension of the possibilities of the instrument.

COUPLED CIRCUITS.

The mathematical theory of coupled oscillatory electric circuits has been admirably and adequately treated by Dr. Hausmann. The application of that theory to a practical case accompanies as a numerical illustration. Those who are at all acquainted with the principles which underlie wireless telegraphy and telephony, realize the importance which attaches itself to the problem of the coupled circuit, and those who claim an interest in the most ingenious product of our modern science cannot fail to understand the significance of the article.

THE INDUSTRIES OF DETROIT.

With his characteristic, pleasing style, Professor Olsen has outlined the industries for which the City of Detroit is famous. He has presented a very suggestive and attractive description of the organizations and equipments of and the processes employed by The Parke Davis Company, The Ford Motor Company, The Acme White Lead and Color Company, and the Pennsylvania Salt Manufacturing Company.

THICKNESS OF FILMS OF SILVER UPON GLASS.

A novel method of determining the thickness of the metal deposits constituting mirror surfaces has been contributed by Professor Irving Fay and Mr. Arthur Rauchfuss. The various means of precipitating homogeneous films of silver on glass, together with the conditions of concentration of the solutions employed, the temperatures, etc., necessary for producing the best results, are given in addition. The article should be of service to engineers and chemists alike.

AN HISTORICAL SKETCH OF THE EARLY DEVELOPMENT OF BRIDGE BUILDING.

CLARENCE W. HUDSON.

One of the most important factors governing the growth of civilization has been the increase in facilities for communication between widely separated portions of the earth. A wide separation did not in early times imply great distance between two points. A high mountain range, a deep gorge, or a river was an effective barrier to all intercourse. Railways and highways would be almost valueless if they could not be continued over gorges and rivers.

It will readily be admitted that the bridge builder's art is a very important and old one. The first bridges, probably, were not constructed by man. Beam bridges of fallen trees, suspension bridges of vines, and arch bridges of natural rock probably existed and were used by the wild animals before man appeared on the earth. By far the greater number of ancient bridges which are described in history were for military purposes. One of the oldest known bridges is the Pons Sublicius, a wooden structure, over the Tiber River. It was built by Ancus Marcus, the fourth Roman king, in the year 621 B.C. It is the same bridge which about one hundred years later was made famous by its heroic defense by Horatius Cocles against the Etruscan king, Lars Porsenna. Contemporary with the Tiber bridge, or perhaps a few years earlier, the Babylonian king Nitocris built a wooden bridge on stone pillars over the Euphrates in Babylon. The fifth Roman king, Tarquinius Priscus (who began the construction of the Catacombs), constructed a stone arch bridge called the Pons Salarius over the Tiber in the year 600 B.C., which is the first stone arch bridge mentioned in history. While they bear very little relation to the development of bridge building, it may be well to mention three historical pontoon bridges. The Persian king

Cyrus built a pontoon bridge over the Meander River in Asia Minor in the year 536 B.C. Darius, the next successor but one to Cyrus, built a pontoon bridge over the Lower Danube in the year 490 B.C. The most famous of all pontoon bridges was built by Xerxes, who was the son of Darius, with Phœnician and Egyptian workmen, in the year 480 B.C., over the Dardanelles, and is known as the Hellespont. It served an army of 2,000,000 soldiers, together with 1,000,000 servants.

The art of bridge building had reached a considerable degree of perfection as long ago as 2000 years. But it is only within recent years that it in any sense could be termed a science. The character of the earlier bridges, a few of which are still standing, shows us very graphically the state of the knowledge of the bridge construction of that period. There are no remains of bridges in existence to-day which are much in excess of 2000 years old; but as there are the remains of a few structures at least 2000 years old and well-authenticated historical reference to many others, it is safe to conclude that some knowledge of the art of bridge building had existed for many centuries before that date. These very early bridges were constructed of timber, brick or stone. The Chaldeans, Assyrians and Egyptians were fairly skilled in the art of brick making. Most of these bricks were sun-dried, but the methods of their manufacture are not well known. Some of the bricks would compare favorably with those of modern times. While there are no known remains of ancient bridges built of bricks, there are the remains of true arches built of bricks of from 12 to 15 ft. span. Pointed sewer arches of brick have been found in what is supposed to be the palace of Nimrod on the Tigris River, possibly of the date 1300 B.C. Excavations at Nippur have revealed a mud-pointed brick arch possibly built 4000 years B. C. These are true arches. During this same period, the false arch was frequently used to span openings. The false arch was a series of overhanging flat stones covered by a central flat stone, as shown in Fig. 1. The true arch, as it is hardly necessary to state, had rings of voussoirs of brick or stone. The form of the arch ring was either pointed or circular. As good stone and timber were abundant, and their practical manipulation well understood, and as the arch principle was used, it is fair to assume that many bridges were in existence. This assumption is also a reasonable one in the light of the known existence of structures 2000 years old. Down to the period which begins about 300 years B. C., the art of bridge building was lacking in any knowledge of mechanics, limited to a very slight knowledge of foundation building, and by a very imperfect knowledge of building materials, and the number of known building materials was small.

About this time one of the most valuable, if not *the* most valuable, of engineering materials was introduced, or at least was first used in a form which survives to the present day. This material is pozzuolana, a volcanic earth, which was made to form the basis of a strong and enduring mortar for masonry joints and a matrix for permanent concrete. This volcanic ash, or earth, when pulverized, makes an excellent hydraulic cement; that is, it will harden and attain great strength under water. Its introduction made possible an almost indefinite development to masonry construction. This development still goes on in our day by means of artificially burned Portland cements.

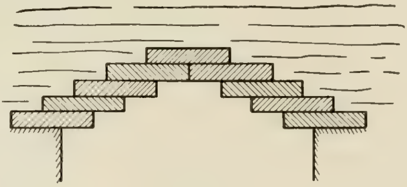
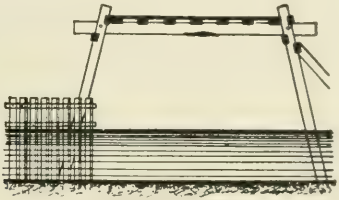


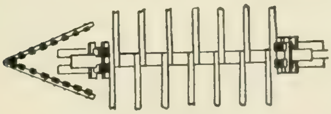
FIG. 1.

The early Romans were excellent engineers in many branches of the profession. In bridge building their engineers were equal to the great demands made on them. Ancient Rome was first located on the left bank of the Tiber (looking down stream). It was soon necessary to bridge the stream. It is now known that seven or eight bridges connected the two shores of the Tiber in ancient Rome. The oldest of these bridges was known as the Pons Sublicius, and has previously been mentioned. This was probably entirely of timber, except possibly the abutments and piers. The best opinion is that the bridge had pile foundations. A flood destroyed the bridge in the year 23 B.C. It was rebuilt and later again destroyed by a flood.

At this time the Romans were skilled in the art of pile driving. In Fowler's book on Ordinary Foundations is given a copy of an old print showing Cæsar's Bridge over the Rhine. This picture shows a pile driver on a float at the outer end of the part of the bridge under construction. This picture, if it has any foundation in fact, gives valuable insight into their ability to handle materials, as a pile driver is a machine of considerable power. A plan and cross-section, at a pier, of Caesar's Bridge is shown in Fig. 2. A derrick is shown (see Fig. 3) in the book of Clemens Herschel, "The Water Supply of The City of Rome," the falls of which were raised by boys walking on the inside of a very large wheel forming a treadmill. About the year 100 B. C. a stone bridge was built over the Tiber about one-half mile above the city of Rome. This bridge was known as the Ponte Molle, and was a series of masonry arches varying from 51 to 79 ft. in span. The width of the bridge was 29 ft.



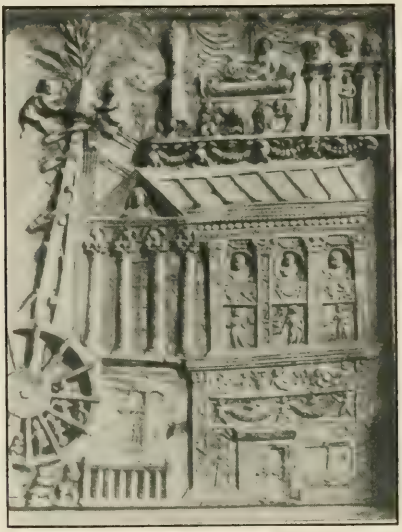
Cross-section at Pier.



Plan at Pier

FIG. 2.

There is not space to describe any other of these ancient Roman bridges, except to say that the Pons Fabricius still exists. It has three arches exposed and a fourth concealed by the modern embankment at one end. A timber bridge was known to occupy the site of this bridge as early as 192 B. C. In the year 62 B. C., Lucius Fabricius, Commissioner of Roads, reconstructed a portion of it into a masonry structure of arches. An engraved inscription below the parapets shows that the work was duly and satisfactorily completed, and further that it was the custom to require the constructors of bridges to guarantee their work for a period of 40 years, as possession of the last portion of the original guarantee was retained until the forty-first year after completion. The bridges of this day, while great advances over those that preceded, show a lack of knowledge of the principles of mechanics, and a lack of knowledge of the strength and properties of materials, except for a few materials, and about these there was little known. Their mechanical appliances were few and not flexible; their methods of transportation were limited. Their knowledge of foundation building was not extensive. Therefore the masonry arch of dimensioned stone, each of small size and in the form of an arch, was their best means of bridge construction, and they used it freely. The Romans during the same period constructed work in other countries than their own—in Switzerland, Spain and France. But there is not space to describe them here.



Roman Derrick.

FIG. 3.

Following the decline of the Roman Empire, there does not seem to have been any advance in the art of bridge building until late in the 18th century, except in the case of suspension bridges. The lack of knowledge of how to build foundations in deep water was a serious handicap to early bridge building. The ancient builders used piers of enormous size founded on the unprepared river bottom, which generally had a very small bearing power. The bridge at Shuster, Persia, over the River Karun, winds across the river in serpentine form, seeking the shallow places for pier foundations.

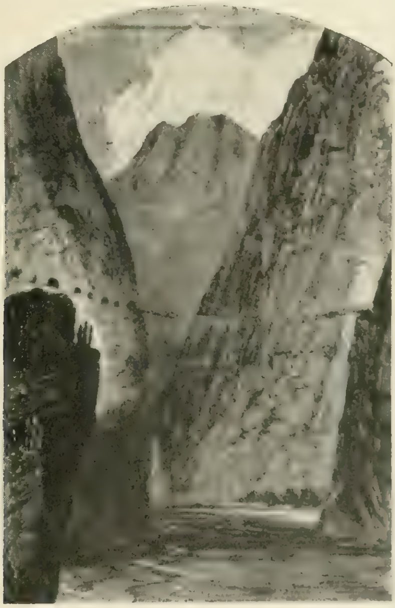


FIG. 4.

That there had been considerable advance in the art of suspension-bridge construction previous to the 18th century is proven by the fact that travelers to the interior of Thibet, Ecuador, Peru, and Chili report the existence of hundreds of such bridges. Fig. 4 shows a suspension bridge described by Humboldt as built in prehistoric times over the Apurimac River in Peru. This river is one of the sources of the Amazon. The cables of the bridge are made of fibrous roots; it has a length of 148 ft. and the roadway is 118 ft. above the river surface. Fig. 5 shows an old bridge in the Caucasus Mountains, described by Hildenbrand, having a span of 80 ft. The cables are made of grapevines, and it appears to have a log as a stiffening truss.

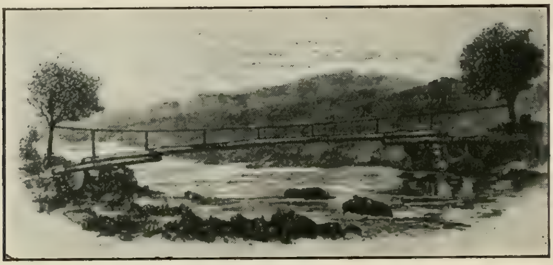


FIG. 5.

The use of the cantilever principle is clearly shown in the next two figures; Fig. 6 is the picture of a log cantilever bridge near Darjeeling, in the Himalaya Mountains, in Northwestern India on the border of Thibet. It is understood that this design has been in use since a remote period. The cut is a reproduction of a photograph brought

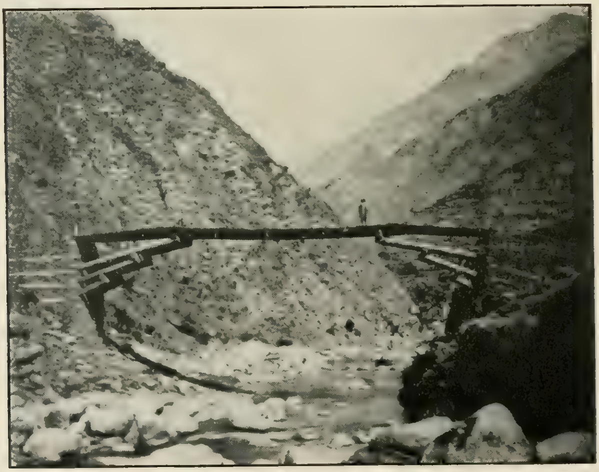


FIG. 6.

to this country by Capt. Joseph A. Leonard, late U. S. Consul at Calcutta, India. Fig. 7 shows a log cantilever near Opdal, in Norway, which is understood to be a very old type.

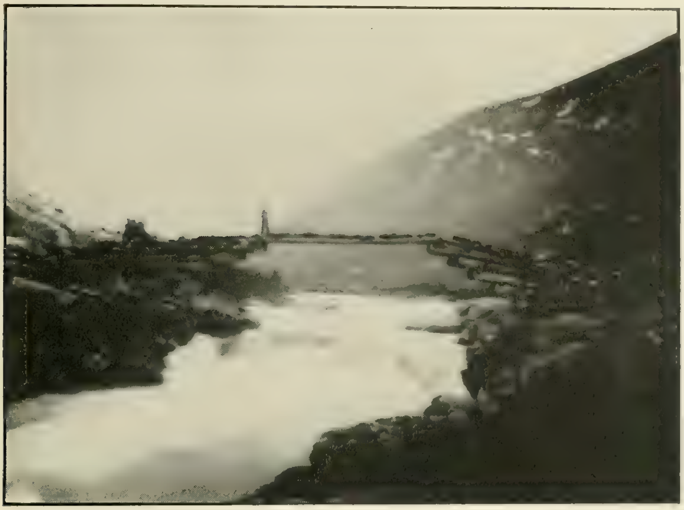


FIG. 7.

The development of the art of bridge construction is distinctly marked by certain periods, during which new theories were evolved, new materials made available, or new mechanical devices originated. The date of the origin of the truss is not known. Palladio's treatise on architecture, published in 1570, contains a drawing of the Cismone Bridge, which had a span of 114 ft. and outline of Fig. 8. Trajan's Bridge, one of the early seven across the Tiber, appears to be a combination truss and arch of timbers. A bas-relief of this bridge, built in 104 A. D., is shown in the Trajan Column in Rome. In Europe small wooden truss bridges have been built for centuries.

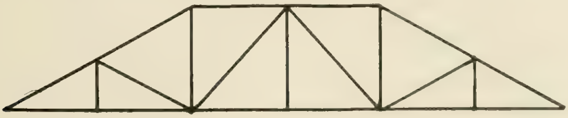


FIG. 8.

The origin of the suspension bridge is also obscure. As we have seen, rope bridges of this type existed in Peru in the time of the Incas, and bridges of the same character were known to exist in Thibet and China at an equally early date. The material of which the early suspension bridges were made was not enduring, and hence our lack of knowledge of the date of their earliest use.

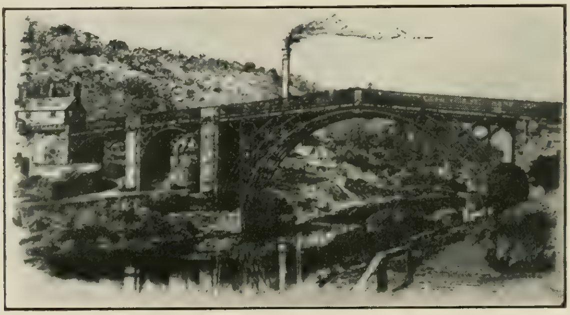


Fig. 9.

England is the country in which the first iron bridge was built, the first one, shown in Fig. 9, consisting of a cast-iron, nearly semicircular arch, having been built in 1776-1779. The bridge had a span of 100 ft. and crossed the Severn River at Coalbrookdale. This bridge is known as the first iron bridge in Europe, but in reality a small iron chain suspension bridge, shown in Fig. 10, for pedestrians was built over the River Tees in 1741.

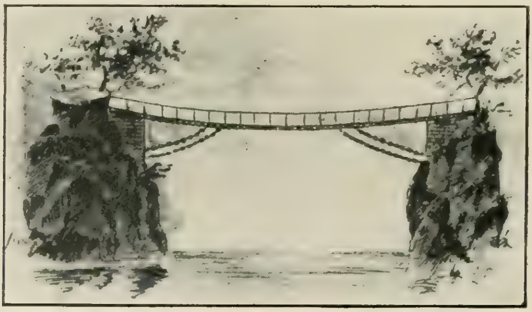


Fig. 10.

The second known iron bridge of the suspension type was built in 1796 by James Finley over Jacob's Creek at Uniontown, Pa. This bridge was a forerunner of a great number of such bridges of very long span. In 1809 Finley built one of his bridges at Philadelphia over the Schuylkill having a span of 306 ft. In 1810, John Templeman, of Washington, D. C., built a suspension bridge over the Merrimac River at Newburyport, Mass. The design was a close copy of the Jacob's Creek Bridge of Finley. The span of the Newburyport Bridge was 244 ft. and the width 47 ft. See Fig. 11.

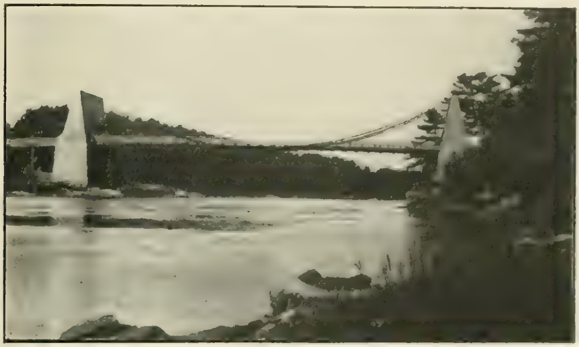


FIG. 11.

In America about the year 1785, Palmer, Burr and Wernwag began to build some remarkable highway bridges of timber. Each of these builders had his own type of bridge, with its own special details. The work was done by contract. The bridges were made according to empirical rules by practical men who had no accurate knowledge of the stresses produced in the various truss members by the loads. These men were of unusual constructive ability and sound judgment, who had to depend upon their own resources and natural instinct, experimenting with models and learning sometimes by failures. Practice precedes science, and science precedes books.

In 1786 Thomas Paine, the well-known author, designed and made a model of a segmental arch. This model was set up in Franklin's house in Philadelphia, whence it was taken to the State House, and eventually was sent to Paris and exhibited at the

Academy of Sciences. Paine had an experimental cast-iron bridge built in England in 1790, and Rowland Burden, in 1793 to 1796, built a bridge at Wearmouth of 240 ft. clear span after this model. This model was the basis of many cast-iron bridges and became the prototype of the modern steel arch. Paine's device was the basis of the design of the Market Street Bridge and the Fairmount Bridge in Philadelphia, both of which were wooden arches. The former was completed in 1800 and the latter in 1812.

The advantages of the application of the theory of mechanics to the design of bridges was not highly thought of in some quarters, at least, during this period. In 1788 Sir Joseph Banks wrote to Thomas Paine in reference to the bridge builders of the period. They "thought with vigor and were not fettered with the trammels of science before they were capable of exerting their mental faculties to advantage," and having no educated "lines of least resistance," they were better able to apply new methods to the problems before them.

As has been before stated, the early bridge builders learned sometimes by their failures; the same may be said of modern builders. One of the worst bridge failures known was that of the Tay Bridge on December 28, 1879. This bridge was originally built in 1871-73, at a cost of $1,100,000. It was 10,321 ft. long, and connected the town of Dundee with the North British Railway on the mainland. It had 85 spans, 13 of which were 245 ft. long each. An entire passenger train with all on board was lost when the 13 long spans, having lengths of nearly 3200 ft., failed simultaneously. The under side of the bridge was 88 ft. above water. Each end of the spans rested on a group of 6 cast-iron columns in the form of a hexagon, and these in turn on cylindrical piers. There was a violent wind storm at the time of the failure, the wind velocity having been probably 90 miles per hour. The piers were not properly designed and the failure occurred in the cast-iron columns.

In this narrative of some of the events in the history of early bridge building I have consulted many authorities, the principal of which are: Burr's Ancient and Modern Engineering, Theo. Cooper's American Railway Bridges, Hildenbrand's History of Suspension Bridge Building, and C. C. Schneider's paper on Bridge Engineering.

When iron was introduced as a bridge-building material a great impetus was given to the art. The 19th century witnessed a great step in the advancement of our knowledge of mechanics, in the development of transportation facilities in the evolution of mechanical appliances, and in foundation building. It also saw the discovery and development of steel making, which by furnishing a cheap and strong material made possible bridges of very long span compared to the earlier types. All of these factors have contributed to the remarkable growth in the art which has taken place in the last century. It is not the purpose of the writer, however, to discuss this point.

> There stands a structure of majestic frame.
>
> —Pope.

THICKNESS OF FILMS OF SILVER UPON GLASS.

Irving W. Fay and Arthur C. Rauchfuss.

Gold, platinum, silver, and other metals in a very finely divided state are black. In order to reflect light and to exhibit their characteristic colors they must cohere into masses or weld themselves together upon the smooth surface of some transparent substance like glass.

Films of metallic silver of great beauty are now deposited on the surface of glass, forming brilliant mirrors. A common and excellent laboratory method consists in pouring together two solutions, one of which shall contain silver in some form and another some substance capable of releasing the silver in a pure metallic state.

In the series of experiments to be described, the solutions were prepared as follows:

Solution A, 90 grams of cane sugar were dissolved in a little water to which 4 c.c. of nitric acid (sp. gr. 1.22) and 175 c.c of ethyl alcohol were added. After thorough shaking, enough water was added to make one liter. This solution does not deteriorate on standing and may be kept for years, while the second solution containing the silver is unstable and should be prepared within a few hours at most of the time of using.

Solution B, 1.8 grams of silver nitrate were dissolved in 180 c.c. of distilled water. Aqua ammonia was added drop by drop until the brown precipitate formed at first was nearly redissolved. To this, 0.9 gram of potassium hydroxide dissolved in the least possible amount of water was added. The brown precipitate that formed was nearly redissolved by adding aqua ammonia drop by drop, care being taken to keep the solution permanently turbid to a slight degree.

In forming a mirror, 10 c.c. of solution A were mixed with 180 c.c. of solution B. To secure rapid and complete mixing of these solutions which alone gives the best results, the small amount of the first solution was poured into the flask or beaker to be silvered and then the larger volume of the silver solution was poured in as rapidly as could be done without spilling. To hasten the deposition of the silver mirror, the flask may be immersed in a larger vessel of hot water. In less than five minutes, a brilliant mirror will appear over the entire inner surface of the flask.

The inner surfaces of ordinary glass vessels are seldom sufficiently clean without special preparation to show perfect mirrors.

The presence of some invisible film of foreign matter on the glass may cause the mirror to appear streaked, or faintly yellow or dull or even dark. If glass is rinsed with hot concentrated nitric acid, washed with water and then treated with a hot solution of stannous chloride in hydrochloric acid and finally rinsed several times with distilled water, it will become chemically clean for this purpose.

Though the process of the actual silvering of glass is comparatively short, the appearance of the bright mirror is preceded by several changes in the mixed liquids. At first the solution darkens; this increases in a minute or more so that the liquid is opaque from black microscopic particles of silver. Gradually the surface of the glass reflects light while still black, very similar to the black mirrors of metallic arsenic deposited upon glass; the black reflecting surface becomes slowly gray and at last patches of the gray become bright with the unmistakable beautiful white color and shining lustre of metallic silver.

This is an instance of separated black particles of silver sticking to the surface of glass and other particles drifting so near the first as to come within the infinitely small distance within which the force of cohesion may work. Particles upon particles become so firmly welded together as finally to form a mass of bright silver. The welding of iron requires a red heat and blows of the blacksmith's hammer; the welding in this instance takes place at the ordinary temperature of the room and under the surface of water without even the aid of an electric current to bring the metallic particles together. It may be termed subaqueous welding. Gold, platinum and other metals exhibit the same property.

For investigation of the thickness of silver films which formed perfect mirrors, glass tubes of uniform bore were selected in which the two solutions described above were quickly mixed and allowed to stand. Thin-walled test tubes about ¾ in. in diameter were cut off at the bottom and the lower ends closed by rubber stoppers. After the silver was deposited, the liquid was poured out, the stoppers were removed and the tubes carefully rinsed and dried. There was a film of definite dimensions easy to measure. The tube was carefully weighed; the diameter of the tube and length of the film were the only data needed to calculate the area. The film of silver was quickly dissolved by immersing it in nitric acid, rinsed with distilled water and dried and weighed. The difference in the two weights, first with the silver and then without it, was the real weight of pure silver which formed the mirror.

The number of grams of silver on a square centimeter were calculated: considering the thickness of 1 gram of water upon 1 sq. cm. was 1 cm. Since silver is 10.53 times denser than water 1 gram of silver would be 1 cm. divided by 10.53 in thickness. Upon this basis, dividing the weight of the silver by the accurately measured area gave the thickness of the film.

1. Film deposited *hot:* the tube was immersed in boiling water for one minute.

Length of mirror	4.4375	ins.
Inside diameter of tube	.923	”
Weight of the tube with mirror	27.0439	grams
Weight of tube without mirror	27.0335	”
Weight of mirror	.0158	”
Area of surface covered by mirror	17.1731	sq. ins.
Weight of silver on 1 sq. cm.	.000142	grams
Thickness of silver film	.0000134	cm.

2. Film deposited from the same strength of solution and under the same conditions as above.

Length of mirror	5.260	ins.
Inside diameter of tube	.890	”
Weight of the tube with mirror	25.3880	grams
Weight of the tube without mirror	25.3742	”
Weight of silver mirror	.0148	”
Area of surface covered by mirror	14.679	sq. ins.

Weight of silver on 1 sq. cm............. .00015 grams
Thickness of silver film.................. .0000147 cm.

3. Thickness of silver film................. .0000169 cm.

4. The silver solution was reduced ½ by adding an equal volume of distilled water.

Thickness of silver film................. .0000072 cm.

5. Full strength of silver solution: heating tube as above for one minute.

Thickness of silver film................. .0000104 cm.

6. The silver solution was again reduced to ½ strength. Heated for one minute.

Thicknes of silver film.................. .0000055 cm.

7. Full strength of silver solution: film deposited cold.

Thickness of silver film................. .0000069 cm.

8. Conditions same as in No. 7.

Thickness of silver film................. .0000075 cm.
9. ” ” ” ” .... .0000058 cm.
10. ” ” ” ” .... .0000070 cm.
11. ” ” ” ” .... .0000038 cm.
12. ” ” ” ” .... .0000045 cm.
13. ” ” ” ” .... .0000017 cm.
14. ” ” ” ” .... .0000021 cm.
15. ” ” ” ” .... .0000056 cm.
16. ” ” ” ” .... .0000036 cm.

The average thickness obtained with the full strength of the silver solution in Nos. 1, 2, 3, 5 by the aid of heat .000014 cm.

Average thickness of the film: silver solution ½ strength and deposited at the room temperature .0000045 cm.

Expressed in millimeters, it would require 7043 silver films deposited hot from a full strength solution to make a millimeter in thickness, and 20,202 films deposited from a half-strength solution at room temperature to equal one millimeter in thickness.

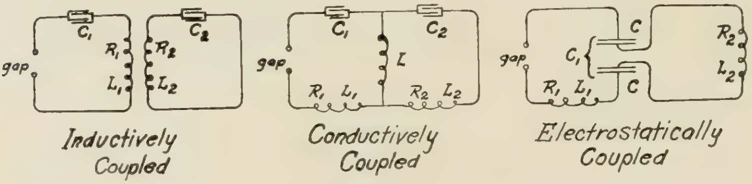
Who teach the mind its proper force to scan
And hold the faithful mirror up to man.

—LLOYD.

OSCILLATION TRANSFORMERS.

ERICH HAUSMANN

The use of coupled circuits or oscillation transformers in wireless communication results in the radiation of greater amounts of energy than is possible with direct-excited antennæ, and is very important for syntonization. Two closed circuits, containing capacity and inductance, so arranged that oscillations set up in one circuit will result in oscillations in the other, may be inductively, conductively, or electrostatically coupled, as shown in Fig. 1. This development of oscillations in the secondary circuit by the primary is accompanied by a reaction of the secondary upon the primary, which reaction is a measure of the degree of coupling: loose coupling, if the influence be small, and close coupling, if large. Two circuits when coupled will not retain their individual isolated frequencies or their damping factors, and it is the object of this article to investigate the change in these factors introduced by coupling. It will also be shown that two such circuits of relatively high resistance individually oscillatory may with close coupling both become aperiodic through association with each other.



Inductively Coupled

Conductively Coupled

Electrostatically Coupled

FIG. 1.

In a single isolated circuit, having the constants R_1 ohms, L_1 henrys, and C_1 farads, the motion of electricity is expressed by

$$\frac{d^2q_1}{dt^2}+\frac{R_1}{L_1}\frac{dq_1}{dt}+\frac{1}{L_1C_1}q_1=0,$$

the solution of which gives the charge at any instant t as

$$q_1=Q_1\varepsilon^{-\beta_1 t}(\cos\alpha_1 t+\frac{\beta_1}{\alpha_1}\sin\alpha_1 t),$$

where $\beta_1 = \frac{R_1}{2L_1}$, $\alpha_1 = \sqrt{\frac{1}{L_1C_1} - \frac{R_1^2}{4L_1^2}}$, and Q_1 is the initial liberated charge. Let $\frac{1}{L_1C_1} = \gamma_1^2$; then $\alpha_1 = \sqrt{\gamma_1^2 - \beta_1^2}$, and for oscillatory discharge γ_1 must be greater than β_1. These circuital characteristics are:

β_1 = damping or attenuation factor;

α_1 = natural oscillation number, or the number of oscillations in 2π seconds performed during discharge in the absence of any impressed electromotive force. Then the frequency is $f_1 = \frac{\alpha_1}{2\pi}$;

γ_1 = free oscillation number, or the number of oscillations in 2π seconds performed during discharge if the circuit were devoid of resistance and occasioned no radiation.

If two such circuits be brought into inductive relation with each other, then, if M is their mutual inductance,

$$\left.\begin{aligned} &\frac{d^2q_1}{dt^2} + 2\beta_1\frac{dq_1}{dt} + \gamma_1^2 q_1 + \frac{M}{L_1}\frac{d^2q_2}{dt^2} = 0, \\ \text{and} \qquad &\frac{d^2q_2}{dt^2} + 2\beta_2\frac{dq_2}{dt} + \gamma_2^2 q_2 + \frac{M}{L_2}\frac{d^2q_1}{dt^2} = 0. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Let the particular solution be $q = \varepsilon^{mt}$, and take

$$q_1 = a_1\varepsilon^{mt},$$
$$q_2 = a_2\varepsilon^{mt}.$$

Substituting these and their time differential coefficients in (1), there result,

$$(m^2 + 2\beta_1 m + \gamma_1^2)a_1\varepsilon^{mt} + \frac{M}{L_1}m^2 a_2\varepsilon^{mt} = 0,$$

and

$$(m^2 + 2\beta_2 m + \gamma_2^2)a_2\varepsilon^{mt} + \frac{M}{L_2}m^2 a_1\varepsilon^{mt} = 0.$$

Eliminating $a_2\varepsilon^{mt}$, simplifying, and clearing of fractions,

$$(1-\rho)m^4 + 2(\beta_1+\beta_2)m^3 + (\gamma_1^2+\gamma_2^2+4\beta_1\beta_2)m^2 + 2(\beta_1\gamma_2^2+\beta_2\gamma_1^2)m + \gamma_1^2\gamma_2^2 = 0, \quad (2)$$

where

$$\rho = \frac{M^2}{L_1L_2} = \text{coefficient of coupling.}$$

The exact solution of this quartic is difficult, but numerous investigators, notably Oberbeck, Wien, Drude, Cohen, Stone, and Kalähne, have obtained accurate solutions for special cases, particularly for zero resistance.

and also approximate solutions for the general case of coupled circuits. The method of Stone gives a very close approximation even for closely-coupled circuits having high damping, and is not unwieldy for numerical calculations. Applying this method, two new circuits are selected which, when isolated, have the same circuital characteristics as the two coupled circuits under consideration. Thus the equation for these equivalent circuits, obtained from (2) by placing $\rho=0$ because the mutual inductance vanishes, and by writing B for β and Γ for γ, is

$$m^4+2(B_1+B_2)m^3+(\Gamma_1^2+\Gamma_2^2+4B_1B_2)m^2+2(B_1\Gamma_2^2+B_2\Gamma_1^2)m+\Gamma_1^2\Gamma_2^2=0, \quad (3)$$

where, by comparing coefficients of like powers of m,

$$\left.\begin{aligned} (1-\rho)(B_1+B_2)&=\beta_1+\beta_2, \\ (1-\rho)(\Gamma_1^2+\Gamma_2^2+4B_1B_2)&=\gamma_1^2+\gamma_2^2+4\beta_1\beta_2, \\ (1-\rho)(B_1\Gamma_2^2+B_2\Gamma_1^2)&=\beta_1\gamma_2^2+\beta_2\gamma_1^2, \\ (1-\rho)(\Gamma_1^2\Gamma_2^2)&=\gamma_1^2\gamma_2^2. \end{aligned}\right\} \quad . \quad . \quad . \quad (4)$$

The second equation of (4) may be rewritten as

$$(1-\rho)(\Gamma_1^2+\Gamma_2^2)=\frac{1+\dfrac{4\beta_1\beta_2}{\gamma_1^2+\gamma_2^2}}{1+\dfrac{4B_1B_2}{\Gamma_1^2+\Gamma_2^2}}(\gamma_1^2+\gamma_2^2).$$

In practice, the fraction of the second member is very slightly different from unity, so that very approximately,

$$(1-\rho)(\Gamma_1^2+\Gamma_2^2)=\gamma_1^2+\gamma_2^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The degree of equivalence can be ascertained for any case under consideration and applied to the results if desired.

Solving the equations of (4) and (5), there result as the circuital characteristics of the two equivalent isolated circuits in terms of their individual constants:

$$\left.\begin{aligned} \Gamma_1^2&=\frac{\gamma_1^2+\gamma_2^2+\sqrt{(\gamma_1^2+\gamma_2^2)^2-4\gamma_1^2\gamma_2^2(1-\rho)}}{2(1-\rho)}; \\ \Gamma_2^2&=\frac{\gamma_1^2+\gamma_2^2-\sqrt{(\gamma_1^2+\gamma_2^2)^2-4\gamma_1^2\gamma_2^2(1-\rho)}}{2(1-\rho)}; \\ B_1&=\frac{\beta_1+\beta_2}{2(1-\rho)}+\frac{(\beta_1+\beta_2)(\gamma_1^2+\gamma_2^2)-2(1-\rho)(\beta_1\gamma_2^2+\beta_2\gamma_1^2)}{2(1-\rho)\sqrt{(\gamma_1^2+\gamma_2^2)^2-4\gamma_1^2\gamma_2^2(1-\rho)}}; \\ B_2&=\frac{\beta_1+\beta_2}{2(1-\rho)}-\frac{(\beta_1+\beta_2)(\gamma_1^2+\gamma_2^2)-2(1-\rho)(\beta_1\gamma_2^2+\beta_2\gamma_1^2)}{2(1-\rho)\sqrt{(\gamma_1^2+\gamma_2^2)^2-4\gamma_1^2\gamma_2^2(1-\rho)}} \end{aligned}\right\} \quad . \quad (6)$$

Since equation (3) is the product of the two quadratics,

$$m^2+2\mathrm{B}_1m+\Gamma_1{}^2=0,$$

and

$$m^2+2\mathrm{B}_2m+\Gamma_2{}^2=0,$$

its solution is

$$m=-\mathrm{B}_1\pm\sqrt{\mathrm{B}_1{}^2-\Gamma_1{}^2} \quad \text{or} \quad -\mathrm{B}_1\pm j\mathrm{A}_1,$$

and

$$m=-\mathrm{B}_2\pm\sqrt{\mathrm{B}_2{}^2-\Gamma_2{}^2} \quad \text{or} \quad -\mathrm{B}_2\pm j\mathrm{A}_2.$$

The frequencies are, therefore,

$$F_1=\frac{\mathrm{A}_1}{2\pi} \quad \text{and} \quad F_2=\frac{\mathrm{A}_2}{2\pi}.$$

Hence the solutions of equations (1) giving the instantaneous charges in the two equivalent isolated circuits of the coupled circuits are

$$\left.\begin{aligned} q_1 &= a_1\varepsilon^{mt}=G_1\varepsilon^{(-\mathrm{B}_1\pm j\mathrm{A}_1)t}+H_1\varepsilon^{(-\mathrm{B}_2\pm j\mathrm{A}\ )t} \\ &=\varepsilon^{-\mathrm{B}_1t}(G_1'\cos \mathrm{A}_1t+jG_1''\sin \mathrm{A}_1t)+\varepsilon^{-\mathrm{B}_2t}(H_1'\cos \mathrm{A}_2t+jH_1''\sin \mathrm{A}_2t), \\ &\text{and} \\ q_2 &= \varepsilon^{-\mathrm{B}_1t}(G_2'\cos \mathrm{A}_1t+jG_2''\sin \mathrm{A}_1t)+\varepsilon^{-\mathrm{B}_2t}(H_2'\cos \mathrm{A}_2t+jH_2''\sin \mathrm{A}_2t); \end{aligned}\right\} \quad (7)$$

and reveal the fact that in each circuit there are two distinct oscillations of different frequencies and damping factors. The constants G and H are evaluated from terminal conditions, for when $t=0$, then $q_1=Q$, $q_2=0$, $\frac{dq_1}{dt}=I_1=0$, and $\frac{dq_2}{dt}=I_2=0$. Hence

$$G_1'+H_1'=Q,$$

$$G_2'+H_2'=0,$$

$$\mathrm{B}_1G_1'+\mathrm{B}_2H_1'=j(\mathrm{A}_1G_1''+\mathrm{A}_2H_1''),$$

and

$$\mathrm{B}_1G_2'+\mathrm{B}_2H_2'=j(\mathrm{A}_1G_2''+\mathrm{A}_2H_2'').$$

These, in connection with equations (1), enable the determination of all the constants in (7), but their expressions are very complicated. We are not concerned particularly with the actual instantaneous current and voltage values, but more so with the variation of the damping factors and periodicities with the coupling coefficients.

As a numerical illustration consider an inductively-coupled oscillation transformer with relatively large resistance and having the following constants:

$R_1=20$ ohms, $R_2=40$ ohms;
$L_1=10^{-6}$ henrys, $L_2=2\times10^{-5}$ henrys;
$C_1=10^{-9}$ farads, $C_2=5\times10^{-9}$ farads.

Their individual circuital characteristics are, therefore,

$\beta_1 = 10^7$, $\beta_2 = 10^6$;
$\gamma_1^2 = 10^{15}$, $\gamma_2^2 = 10^{13}$;
$f_1 = 4{,}775{,}000$ cycles, $f_2 = 477{,}500$ cycles.

The equivalent isolated characteristics for various degrees of coupling, calculated according to the equations (6), are given in the following table, and these values are also presented graphically in Fig. 2:

ρ	B_1	B_2	Γ_1	Γ_2	F_1	F_2
0	9,540,000	1,460,000	31,620,000	3,162,300	4,800,000	446,000
.1	10,720,000	1,500,000	33,350,000	3,160,800	5,020,000	443,000
.2	12,180,000	1,560,000	35,390,000	3,159,300	5,300,000	438,000
.3	14,060,000	1,640,000	37,850,000	3,157,500	5,590,000	429,000
.4	16,570,000	1,750,000	40,910,000	3,156,600	5,950,000	418,000
.5	20,100,000	1,900,000	44,840,000	3,154,500	6,390,000	401,000
.6	25,360,000	2,140,000	50,150,000	3,153,000	6,890,000	368,000
.7	34,150,000	2,490,000	57,940,000	3,151,200	7,450,000	307,000
.8	51,770,000	3,230,000	70,990,000	3,149,600	7,750,000	0
.9	104,500,000	5,500,000	100,450,000	3,148,100	0	0
.99	1053,900,000	46,100,000	318,000,000	3,146,400	0	0

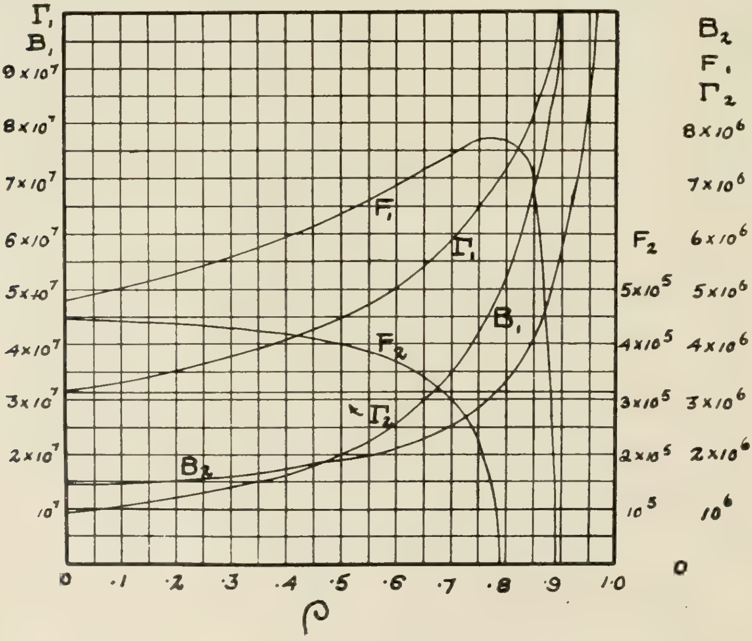


FIG. 2.

It will be observed that the free periodicities $\frac{\Gamma_1}{2\pi}$ and $\frac{\Gamma_2}{2\pi}$ differ from the natural frequencies F_1 and F_2, especially when the coupling is close. When ρ is 0.79, one circuit becomes aperiodic, since $F_2=0$. For closer coupling, the circuits have only one natural frequency of oscillation, namely, F_1; for still closer coupling, both circuits are aperiodic and no oscillations result. Thus, two circuits independently non-aperiodic may both become aperiodic through association with each other.

With close-coupled circuits having lower resistance than assumed in this example, only one will become aperiodic even when the coupling is perfect, that is, for $\rho=1$. Low resistance is the usual condition.

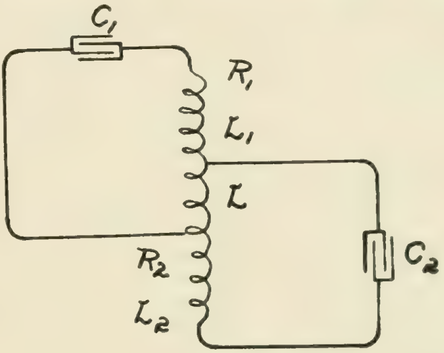


FIG. 3.

In practice, loose-coupled oscillators are usually operated at or near coincidence of their coupled natural frequencies F_1 and F_2; or when closely coupled are operated at some different frequency which gives maximum potential or current in one of the circuits.

The foregoing expressions have been deduced for two circuits coupled inductively, but they are also applicable for other types of oscillation transformers. For conductive coupling, Fig. 1, with the common path of practically zero resistance (a condition always realized in such arrangements), replace $\frac{M}{L_1}$ by $\frac{L}{L+L_1}$ and $\frac{M}{L_2}$ by $\frac{L}{L+L_2}$, and take $\rho_1=\frac{R_1}{L+L_1}$ and $\rho_2=\frac{R_2}{L+L_2}$. In electrostatic coupling, the capacity C_1 may be considered the resultant of three condensers in series, the middle one of which is common to both circuits, thus, $c_1=\frac{1}{\frac{2}{c}+\frac{1}{c_2}}$.

Oscillation transformers may also be coupled both conductively and inductively, as shown in Fig. 3. Let M_1 be the mutual inductance between the common and first branch, M_2 the mutual inductance between the common and second branch, and M_{12} the mutual inductance between the first and second branches. The equations (1) are then modified so that the terms involving M are replaced respectively by

$$\frac{L+M_1}{L_1}\frac{d^2}{dt^2}(q_1+q_2)+\frac{M_{12}}{L_1}\frac{d^2q_2}{dt^2},$$

and

$$\frac{L+M_2}{L_2}\frac{d^2}{dt^2}(q_1+q_2)+\frac{M_{12}}{L_2}\frac{d^2q_1}{dt^2};$$

whence they may be written as

$$\left.\begin{aligned}\frac{d^2q_1}{dt^2}+\frac{R_1}{L_1+L+M_1}\frac{dq_1}{dt}+\frac{q_1}{C_1(L_1+L+M_1)}+\frac{M_1+L+M_{12}}{L_1+L+M_1}\frac{d^2q_2}{dt^2}=0,\\ \frac{d^2q_2}{dt^2}+\frac{R_2}{L_2+L+M_2}\frac{dq_2}{dt}+\frac{q_2}{C_2(L_2+L+M_2)}+\frac{M_2+L+M_{12}}{L_2+L+M_2}\frac{d^2q_1}{dt^2}=0.\end{aligned}\right\} \quad . \quad (8)$$

Comparing these equations with (1) it is found that the arrangement of Fig. 3 is the equivalent of two circuits coupled inductively if we take

$$2\beta_1=\frac{R_1}{L_1+L+M_1}, \qquad 2\beta_2=\frac{R_2}{L_2+L+M_2},$$

$$\gamma_1{}^2=\frac{1}{C_1(L_1+L+M_1)}, \qquad \gamma_2{}^2=\frac{1}{C_2(L_2+L+M_2)},$$

$$\frac{M}{L_1}=\frac{M_1+L+M_{12}}{L_1+L+M_1}, \qquad \frac{M}{L_2}=\frac{M_2+L+M_{12}}{L_2+L+M_2}.$$

Various other arrangements can be formed as special cases of Fig. 3. Therefore, the foregoing solution of inductively-coupled circuits is perfectly general and applicable to all of the types mentioned if the circuital characteristics are appropriately interpreted.

Science is like virtue, its own exceeding great reward.

—KINGSLEY.

LATTICE BARS.

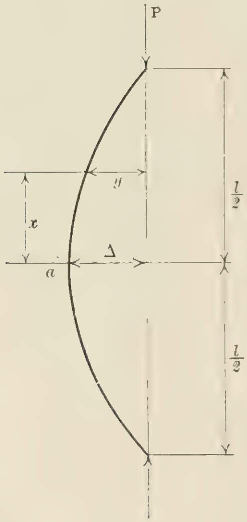
GEORGE W. OXLEY and EDWARD J. SQUIRE

Ever since the disastrous failure of the Quebec Bridge, the subject of column strength has loomed up before the engineering profession as one of extraordinary significance. Many new theories have been advanced and extensive experiments performed in the numerous persistent attempts to solve more clearly the involved problems presented by compression members. C. C. Schneider has made the following weighty statement in the Report of the Quebec Bridge Commission: "The unsatisfactory nature of column formulas is a matter of common knowledge among engineers, but the column formulas may be considered to represent exact science in comparison with the lattice formulas." At the time of the above-mentioned accident, there were no definite specifications in regard to latticing; and Mr. Szlapka, a prominent engineer, reported after a thorough investigation, that the only information he could find concerning the proportioning of column lacing was in Johnson's "Modern Framed Structures." Accordingly, owing to the uncertainty and importance of these matters, a short discussion on proposed theories and existing specifications will not be superfluous.

Latticing or lacing is composed of flat bars, angles, or small channels riveted at the open end of a section and running zigzag from one side to the other to make the parts of the column thus connected act as a unit. Lacing is analogous to the web of a girder or web system of a truss. If there were no bending, such a connection would be unnecessary, as each part would take its proportion of the load; but this ideal condition never occurs in practice, due to the various causes producing initial eccentricity. As a result, uncertain bending is produced which in turn makes the shear, which is dependent thereupon, also indeterminate. Therefore, there are only empirical rules by which the size and spacing of lattice bars can be found. Such bars are designed to transfer shear and act as a lateral support to the web system.

In Appendix C of the Report of the Quebec Bridge Commission, C. C. Schneider has deduced a rational method for analytically dimensioning lattice bars. The failure of a column takes place when the maximum fiber stress reaches the yield-point. In the straight line column formula, $16000-70\frac{l}{r}$, the flexure or bending stress is represented by the expression, $70\frac{l}{r}$, in which l is the length of the member in inches and r is the least radius of gyration in inches. In order to obtain the shear due to bending, the axis is taken properly and the average elastic line assumed as a parabola which lies between the sine curve of an axially loaded column and one approaching a circular curve for a column with an initial eccentricity.

Let x, y = coordinates of any point on parabola;
Δ = maximum deflection;
l = length of column;
P = loading on column;
f = extreme fiber stress due to bending;
I = moment of inertia about axis perpendicular to the plane of lacing;
r = radius of gyration corresponding to I;
d = width of column, i.e., distance out to out of extreme fibers;
a = area of cross-section.



The general equation of a parabola is $y^2=4px$ or $x^2=4py$ if axes are marked in the reverse way. Then remembering that the latus rectum, which equals $4p$, is a third proportional to any abscissa and its corresponding ordinate, we have the equation,

$$x^2=4py=\frac{\left(\frac{l}{2}\right)^2}{\Delta}y,$$

or

$$y=\frac{4\Delta}{l^2}x^2.$$

Differentiating,

$$\frac{dy}{dx}=\frac{8\Delta}{l^2}x.$$

M_a = maximum moment;

$f=70\frac{l}{r}$;

$$M_a=\frac{fI}{\frac{d}{2}}=70\frac{l}{r}\,\frac{ar^2}{\frac{d}{2}}=140\frac{ar}{d}\,l=P\Delta;$$

M = moment at any point $=Py$.

Differentiating,

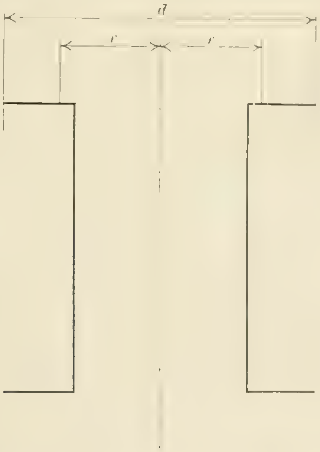
$$\frac{dM}{dx}=P\frac{dy}{dx}=\text{shear}=S.$$

$$S=P\frac{dy}{dx}=P\frac{8\Delta}{l^2}x=P\Delta\frac{8x}{l^2}=140\frac{ar}{d}\,l\frac{8x}{l^2}.$$

When $x=\frac{l}{2}$,

$$S_{\max}=560\frac{ar}{d}. \qquad \dots\dots\dots\dots \qquad (1)$$

Another method of deriving formula (1) is by proportioning the latticing under the assumption of a uniform load applied at right angles to the axis of the column to allow for the shear due to flexure as specified in American Railway Engineering and Maintenance of Way Association Specifications. The nomenclature is the same as above with the addition of w as the assumed uniform load per foot.



$$M_a=\tfrac{1}{8}wl^2=\frac{fI}{\frac{d}{2}}=70\frac{l}{r}\,\frac{I}{\frac{d}{2}}=70\frac{l}{r}\,\frac{ar^2}{\frac{d}{2}}$$

$$\tfrac{1}{8}wl^2 = 140\, l\frac{ar}{d}.$$

Let total load $= W = wl$,

$$\tfrac{1}{8}Wl = 140l\frac{ar}{d};$$

$$W = 1120\frac{ar}{d}.$$

$$S_{\max} = \frac{W}{2} = 560\frac{ar}{d}.$$

Thus the same value for the shear is obtained either under the assumption of a uniform or a concentrated loading. If a different straight line formula were employed, the coefficient of $\frac{ar}{d}$ would change. According to this derivation, the shear decreases toward the middle of the column and is independent of the length.

For single latticing, the area required for one bar,

$$A = \frac{S \sec \alpha}{2k}. \quad \dots\dots\dots\dots \quad (2)$$

where α = angle which the latticing makes with the line perpendicular to the axis and k = unit stress in compression or tension. In order to develop the full strength of a column, every part must be capable of resisting bending. Those bars in compression must be designed to satisfy the column formula while those in tension should have sufficient net area to develop the allowable unit stress.

Substituting for S in formula (2),

$$A = \frac{560}{2k}\ \frac{ar}{d} \sec \alpha; \quad \dots\dots\dots\dots \quad (3)$$

$$A = \frac{280}{16000}\ \frac{ar}{d} \sec \alpha \text{ for tension.}$$

$$A = \frac{280}{16000 - 70\,\frac{l}{r}}\ \frac{ar}{d} \sec \alpha \text{ for compression.}$$

For double latticing, the area would equal one-half that given by formula (3).

As an illustration of the application of this method, consider two 15-inch channels, 55 pounds:

$$\text{Area of two channels} = 32.36 \text{ sq.ins.}$$

$$\frac{P}{a} = 16000 - 70\frac{l}{r}. \qquad \text{Say } \frac{l}{r} = 100.$$

Then

$$P = 32.36 \times 9000 = 291{,}240 \text{ lbs.}$$

Making r the same for both axes, distance back to back of channels is 8.52 ins. and $d = 16.16$ ins. Then substituting in (1),

$$S = 560\frac{ar}{d} = \frac{560 \times 32.36 \times 5.16}{16.16}$$

$$= 5770 \text{ lb.}$$

In a set of new specifications for steel structures, the American Bridge Company has specified that the latticing of compression members should be proportioned to resist a shearing stress equal to 2 per cent of the direct stress. In a recent editorial in the *Engineering Record* comment has been made upon this as follows: "Under details of compression members, the requirement that latticing should be designed for a shearing stress equal to 2 per cent of the direct stress is a great improvement over other specifications, and it is of interest that this clause was proposed as long as twenty-two years ago by Mr. H. S. Pritchard in an article in the "*Lehigh Quarterly*.""

Applying this specification to above case,

$$P = 291{,}240 \text{ lbs.,} \qquad 2 \text{ per cent } P = 5824.8 \text{ lbs.}$$

This value for the shear is very close to that obtained by means of the formula. Computing for area required, we obtain 0.208 sq.in. for which a bar $2\frac{1}{2} \times \frac{3}{8} = 0.56$ sq.in. will suffice. $2\frac{1}{2}''$ is the minimum width for $\frac{7}{8}$ in. rivets and $\frac{3}{8}''$ is the minimum allowable thickness of plate. Thus it may be concluded that the present specifications are pretty rigid: and, for ordinary practice, the use thereof is perfectly justifiable.

In *Engineering News*, November 7, 1907, Professor Clyde T. Morris, of Ohio State University, has suggested an approximate formula under the assumption that the moment diagram is a straight line, that is, that the increment of stress per unit of length is a constant and further assumes that the stress in the extreme fibers of each side is uniformly distributed over the cross-section. With such hypotheses, he derives the value of the shear as

$$\frac{70lam}{2l'rn},$$

in which m = distance between rivet lines in lacing of two parts;
l' = distance within which the total stress is transferred by the lacing;
n = number of lattice bars in each panel.

With round ends,

$$S=2\times 70\,\frac{am}{rn}.$$

Using this formula gives a greater stress than the one derived above, so that this would not be as economical as those previously investigated.

In the *Western Society of Engineers' Journal*, June, 1908, W. C. Armstrong has assumed the tie-plates to take one-quarter of the shear and the lacing three-quarters, and therewith derives the expression,

$$S=1.5\,\frac{kI}{d'l'n},$$

where d' = depth of leaf and the other symbols are the same as above.

Other formulæ have been deduced allowing for eccentric loading and variation in the ends, but the best theoretical formula at the present time is equation (1), in which the shear is independent of the length and the load.

Every standard set of specifications at the present time carefully requires certain definite spacing and dimensioning of lattice bars. In general, the width varies from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches, depending upon the size of the rivets. The thickness of single latticing must be at least one-fortieth the distance between rivets, that of double latticing, one-sixtieth. Double latticing is used when the distance between rivet lines in the flanges is more than 15 ins. and is riveted at intersection. The angle made with the axis of the member should not be less than 60° for single and 45° for double latticing. Minimum thickness is generally specified as $\frac{3}{8}$ in. The Osborn Engineering Company uses angles if thickness exceeds $\frac{7}{16}$ inch.

Lattice bars, batten plates, and connections weigh about 30 per cent of the weight of heavy columns and about 50 or 60 per cent in the case of light structures. In general, the obliquity depends upon the inequality in the end eccentricities. Two channels are usually placed so far apart that the tendency of the column will be to deflect in the plane of the web.

Lattice formulas and specifications determine to a certain extent the value of the extreme fiber stress in the lacing, but, as the Report of the Quebec Bridge Commission expresses it, "Only tests and experience can determine whether these give economical and safe results." For ordinary work, the existing theory is sufficiently rigid and economical; but, for unusual cases, new feats in engineering, such as the immense compression members of the Quebec Bridge, as much attention should be given to the proportioning of latticing as to the design of the cross-section. In conclusion, therefore, it is clearly seen that the design of a lattice system depends on the judgment of the engineer guided only by experience. The best experimental work performed on this subject has been that by the Phœnix Bridge Company on the test of the model compression member of the Quebec Bridge and also the series of tests made at the University of Illinois Experiment Station. As bibliography on this subject, the reader is referred to University of Illinois Bulletin No. 44, "Investigation of Built-up Columns," by Talbot and Moore; Quebec Bridge Report; and The Proceedings of the American Society of Civil Engineers.

With busy hammers, closing rivets up,
Give dreadful note of preparation.

SHAKESPEARE.

THE INDUSTRIES OF DETROIT.

JOHN C. OLSEN.

I had the pleasure of inspecting a number of chemical plants in Detroit, on the occasion of the fifth annual meeting of the American Institute of Chemical Engineers, and saw a number of interesting chemical operations in plants to which permission to visit had never before been granted.

The first plant visited was that of Parke, Davis & Co., where drugs and pharmaceutical preparations of all kinds are manufactured. This is the largest factory of its kind in the world, and in it something like 10,000 chemical compounds and drugs are produced. The organization and chemical control of a plant of this magnitude is exceedingly complex and difficult. The laboratory in which most of the routine tests are made and new preparations investigated is a four-story building of imposing size. It is completely divided into numerous small laboratories. The halls are lined with cases containing chemicals and samples of all kinds.

I was particularly interested in the method of testing the strength of adranelin, which is a very powerful heart stimulant. A dog was chloroformed and a glass tube connected to one of his arteries, and this tube connected to a manometer containing mercury. This in turn was connected to a delicately poised arm with a pointer, which made a mark on a cylinder covered with lamp black. Each beat of the heart produced changes in the blood pressure, which moved the mercury in the manometer, thus causing the arm to vibrate and to produce an up-and-down stroke on the carbon-coated cylinder. The ordinary heart beat produced a stroke about a quarter of an inch long. 1 c.c. of adranelin of standard strength was then injected into the blood of the dog, which stimulated the heart so that the stroke of the pointer was increased to about an inch. When the pointer again made the normal stroke, 1 c.c. of the adranelin to be tested was injected and the length of the stroke noted. If this was not equal to the standard, additional quantities were injected until the stroke of the pointer was equal to that used when 1 c.c. of the standard solution had been injected. In the test which I observed, it required 1–7/10 c.c. of the solution being tested to give the same stimulation to the heart as produced by 1 c.c. of the standard solution. It would, therefore, be necessary to concentrate the solution being tested from 1-7/10 to 1 c.c. in order that it might be of standard strength.

I cannot take the time to describe the many interesting operations seen, but it seemed that everything was made in the plant which might be used in the manufacture of any drugs or in their shipment or sale. We found a complete printing establishment, including typesetting machines, presses and bindery, in which all the catalogues and printed matter are prepared. We also found that all the glass tubing and other receptacles used in putting up drugs are blown in another department of the plant.

I next visited the works of the Ford Motor Company. Detroit is the home of the motor-car industry. Something like nineteen factories are busily engaged in turning out these machines, and in addition almost unnumbered plants where accessories and special parts are manufactured.

Detroit is a beautiful city with many miles of broad asphalt paving and beautiful homes.

The Ford plant is probably the most wonderful shop of its kind in the world. Its organization is something truly surprising. The machine shop alone is about one thousand feet wide and half a mile long. This gives a floor space of over eighty acres, which is the equivalent in area of a good-sized farm. The shop contains all the necessary machinery, including lathes, drills, and planers, as close together as they could possibly be placed, and allowing only space enough for the operator to stand and have his small supply of raw material on one side and the finished product on the other. Standing anywhere near the center of this room, one looks through a forest of belts without seeing the end in any direction. Many of the operators have three or four drills, which are taken care of in turn. The shop turns out one hundred and fifty thousand cars per year, or three hundred and eighty cars every day of eight working hours. In spite of this large number of cars finished every day, we did not see fifty finished, for as soon as each is completed it is moved to the loading platform between a line of freight cars, pushed aboard and shipped away for sale. Steel or other material which comes in on Monday is sent out as a finished car not later than Thursday. In many cases, raw material coming in in the morning is sent out as a finished car in the evening of the same day. I was surprised at the very small amount of raw material or finished parts that were to be seen throughout the plant. Everything is so thoroughly organized that only a keg or two of a given size of bolts can be seen at any one time. The plant employs 8500 men, which seems small as compared with the output they produce. This again shows the marvelous organization of the plant. Eight hundred thousand dollars' worth of new machinery was being installed at the time of my visit.

It is cheaper to send cars "knocked down" than intact. For this reason, a large part of the output of the plant is sent to assembling plants in different parts of the United States and England. Six of these shops, costing $250,000 apiece, have been constructed or are under construction in the United States and one such is in operation in England.

Fifteen years ago Mr. Ford was a machinist earning $3 a day. He was known in Detroit as "Crazy Ford." He was working on automobiles, and once constructed a machine which would frequently go backwards when started instead of forward. He took it back to his shop for another month or two and then brought it out in such a condition that it would go the way he wanted it to. To-day his factory is putting out 150,000 cars per year at $600 to $800 apiece. This represents an annual business of one hundred million dollars. He owns 54% of the stock of his plant. His financial management is so perfect that all material is paid for in cash and all discounts for cash obtained.

From the Ford Motor Company's plant I was taken to the works of the Acme White Lead and Color Company. Here ready-mixed paints and dry colors are made by processes similar to those used by the Devoe & Raynolds Company in Brooklyn. I thought in many ways that the plant of the Devoe & Raynolds Company was better equipped than that of the Acme White Lead and Color Company. The most interesting thing seen at this plant was a process for making lead carbonate or white lead. It is known as the Acme Mild or Rowlley process.

The lead is melted and forced through an atomizer into a steel cylinder some 6 ft. in diameter and 15 ft. long. A lead mud results from this process, which constitutes what might be called powdered lead, containing, as it does, only a few particles as large as a pin-head. This powdered lead is mixed with water and placed in tanks, where it is agitated. Air is meanwhile blown in. The lead very quickly absorbs oxygen and is converted into an hydroxide, about 80% being so converted. The lead hydroxide is fine and light, while metallic lead is quite heavy. On allowing the material to settle for a short time, the metallic lead sinks to the bottom. Thus the floating hydrate can be carried by a stream of water to an adjoining vat, there to undergo the next step in the process.

The metallic lead is carried to the roaster, where it is converted into litharge. Carbon dioxide is blown into the water containing the hydrated lead, converting it into hydrated lead carbonate or white lead. The carbon dioxide is obtained from furnaces where coke is burned. The gas is purified before being blown into the lead hydrate. For this reason the carbon dioxide costs practically nothing. A very excellent grade of white lead is obtained. No information could, of course, be obtained as to the economy of the process, but it is probably cheaper than the Dutch lead process, which is largely used by the National Lead Company.

I next entered the Pennsylvania Salt Manufacturing Company's plant. There are a number of salt and alkali companies located in the southern part of Michigan. The choice of this location is due to the fact that the entire southern part of the State of Michigan is underlaid by thick salt beds of remarkable purity. The beds are from a few hundred to a thousand feet beneath the surface. There is one bed 90 ft. thick composed of solid salt. This is brought to the surface by means of wells which are bored to admit of a 6-in. pipe being forced down to the top of the salt bed. A 3-in. pipe is then inserted and driven down to the bottom. The Pennsylvania Salt Manufacturing Company's wells are 1230 ft. deep. Water is forced down the 3-in. pipe at a pressure of 175 lbs. per square inch. On reaching the salt bed it becomes saturated with salt, and this brine is forced to the surface through the larger pipe. It carries about 305 grams of salt per liter. A well does not give satisfactory service until it has been pumped for some considerable time and a cavity produced at the bottom. After that there is no difficulty in securing plenty of concentrated brine. When forced, a single well will produce 27 tons of salt per day. It is customary to drill the wells about 400 ft. apart. Of course all the wells go into the same bed of salt, and in time the water will dissolve out the salt between the two adjacent shafts, so that there will be underground communication. This fact is ascertained by obtaining brine from one well when water is forced into the other. The Pennsylvania Salt Manufacturing Company has two wells which are connected in this way. They are 12 to 13 years old. No well has ever yet been exhausted. The brine is evaporated in large vacuum stills which operate continuously. The salt drops out at the bottom and is clean and glistening white. It is over 99½% pure.

A great quantity of the salt is used to manufacture chlorine and caustic soda. This is carried out in electrolytic cells. I was permitted to look into the room containing these cells, but was not allowed to inspect them.

The chlorine is used to manufacture bleaching powder, and it is also liquified for use in the Goldschmidt detinning process. The Goldschmidt Company has a plant at Wyandotte near the salt works and also a number of other plants, one of them in New Jersey. The liquid chlorine is shipped in tank cars and is used to remove the tin from tin scrap.

The pots for the concentration of caustic soda are made of cast iron containing 4% of manganese. They are 10 ft. in diameter and 7 ft. deep, the thickness of the iron being 2¼ to 3 ins. Each pot weighs 13 tons. The pots are circular in shape, very much like a platinum dish. They are set in circular brick work with a grate at one side and underneath, so that a coal fire can be built on the grate and the hot gases passed underneath and around the pot except in the center, where a pillar of brick work is constructed upon which the pot rests. The pots have sheet-iron covers with small openings, which are covered with lids. Each pot will hold 18 tons of finished caustic soda. Dilute caustic soda solution is run into the pot and the fire started. It boils quite vigorously, and as it concentrates, more dilute caustic is run in and the evaporation continued until the pot is full of pure caustic. The temperature, of course, must be raised as the solution concentrates. The finishing heat is 475° to 550° C. At this temperature powdered sulphur thrown on the surface burns rapidly with a blue flame. The liquid caustic soda is transparent and the red-hot iron pot can be seen through the caustic soda. The fire must be very hot to maintain this large pot at this temperature, and the pot blisters where the flame strikes it. In order to increase the life of the pot, it is lifted by means of a crane and turned through 1/12 of 360° each time it is emptied. It takes something like a week to finish a batch of caustic soda. A pot will not produce more than 25 or 30 batches of caustic soda. Generally one or more holes develop where the thick iron is eaten away. When the caustic soda is sufficiently concentrated, the cover is removed and the pot's content allowed to freeze over; that is, a layer of solid caustic soda about an inch thick is permitted to form on top. This solid caustic is broken and it then settles to the bottom, solid caustic soda being heavier than liquid caustic. The impurities have settled to the bottom during the concentration of the caustic and this layer of solid caustic covers the impurities at the bottom, so that the pure liquid above can be ladled out. It is poured into sheet-iron drums and allowed to solidify. The drums are cut open by those who purchase and use them, or, in some cases, steam is blown into the drums and the soda melted out. This leaves the drum intact.

A small portion of the caustic soda is powdered and put up in various sized tin cans for retail sale. The Pennsylvania Salt Manufacturing Company has been in the business of selling caustic soda in small cans for a good many years.

I saw also at the Pennsylvania Salt Manufacturing Company's plant the manufacture of alum. Ground bauxite is charged into lead-lined wooden tanks and fairly concentrated sulphuric acid poured in. The bauxite dissolves very readily in sulphuric acid, producing aluminium sulphate. This solution is then diluted and filtered and then concentrated in lead-lined tanks. Towards the end of the operation, the requisite amount of freshly precipitated aluminium hydrate is added for the purpose of neutralizing the slight excess of acid so as to produce an alum which is slightly basic. When the proper concentration is reached, the fused aluminium sulphate is poured out on a cement floor, which is covered with powdered alum in order to prevent the mass from sticking when it cools. The solidified alum is then broken up and powdered. It is shipped, in barrels, for use in purifying water.

In every rank, or great or small,
'Tis industry supports us all.

—Gay.

TITLES OF THE THESES PRESENTED TO THE FACULTY OF THE POLYTECHNIC INSTITUTE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES CONFERRED IN JUNE, 1912.

BACHELOR OF SCIENCE IN CHEMISTRY

Everitt Judson Cole	The Delicacy of Flame Reactions.

CHEMICAL ENGINEER

Daniel Alfredo Melhado	Determination of Potassium by Cobalti-Nitrite.
Abraham Elias Ratner	The Oxidation of Linseed Oil.

CIVIL ENGINEER

Stuart Markell Brown	Design of a Single Track Elevated Railroad Structure for Remsen Street, Brooklyn, N. Y.
Joseph Anthony Cattano, B.E.	The Evolution of the Settling Tank.
Joseph Albert Dalen, M.Ph.	Investigation of the Concrete Steel Arch Bridge at Seeley Street, Brooklyn, N. Y.
David Israel Davidson, B.S.	The Newsprint Paper Plant.
Sidney Phillip Delemos, B.S.	Design of a Sanitary Sewage System and Disposal Plant for Sea Cliff, N. Y.
Phillip Goldstone, B.S.	Water Hammer in Pipe Lines.
Charles Greenfield	An Investigation for the Design of a Reinforced Concrete Aqueduct.
Jacob Samuel Hyman, B.S	The Design of a 200 Foot Span Single Track Through Railroad Bridge.
Frederick Henry Mellert, B.S.	The Construction of the Flatbush Avenue Station of the Fourth Avenue Subway.
Jacob Kramer	Moments, Shears, and Floor Beam Concentrations for Plate Girder Bridges for Cooper's *E* 50 Loading.
Edward Nuebling	The Detection of Leakage in Water Supply Systems.
George Woods Oxley	A Theoretical and Experimental Study of Steel Columns.

Abraham Rosenzweig	Moments, Shears, and Floor Beam Concentrations for Plate Girder Bridges for Cooper's *E* 50 Loading.
Joseph Schlam	Design of a Single Track Through Riveted Railroad Bridge of 129 Foot Span.
Charles Meyers Schultz, B.S.	The Preliminaries for the Design of a Pier on Piles.
David Alfred Sealey, B.E.	The Elimination of a Grade Junction.
Nathan Warren Shapiro, B.S.	An Investigation for the Design of a Reinforced Concrete Pressure Aqueduct.
George Herbert Shaw	The Design and Construction of the Steel Pipe Siphons of the Catskill Aqueduct.
Theodore Clinton Towl	Meters for Natural Gas.
Morgan Lewis Woodruff	A Theoretical and Experimental Study of Steel Columns.

CIVIL ENGINEER
CUM LAUDE

Frank Clarence Johnson	Methods of Valuation of Railway Property.

ELECTRICAL ENGINEER

Harry Knight Beasley	The Design and Construction of a Three K.V.A., Three Phase Transformer.
William Claude Fisher, M.E.	Measurement of Losses and Steam Consumption on 750 Kilowatt Allis-Chalmers Condensing Turbine.
Edward Seymour Fromovitz	An Investigation of High Tension Phenomena.
Ernest Linwood Ganter	Study of Small Sparking Distances and the Kinetic Energy of Electrons.
George William Janson	An Investigation of High Tension Phenomena.
Frederick Eugene Jaquay	The Operating Characteristics of Dynamotors, Motor Generators and Balancers.
Samuel Kaplan	A Variable Load Reactor.
Walter Abbot Phelan	An Investigation of the Theory and Operation of the Murphy Electricity Rectifier.

ELECTRICAL ENGINEER
CUM LAUDE

Monroe George Woolfson	Electric Power Transmission and Distribution.

MECHANICAL ENGINEER

William Frederick Brendlin, B.S.	The Design of the New Jersey Zinc Co.'s Ore Dressing Mill No. 2, at Franklin Furnace, N. J.
Russell Grover Brown, B.S.	
Henry Priester, B.S.	Flat Plates.
Arthur Seubert	
William Hewton Thompson, B.S.	Flat Plates.
George William Weitlauf	
Charles Bertrand Worthen	

MASTER OF SCIENCE

John Joseph Johnson, B.S., C.E.	An Investigation of Forms for a Flat Arch by the Elastic Theory.
Hazen Greeley Tyler, E.E.	The Principle of Relativity.

THE VECTOR DIAGRAMS OF ELECTRIC DISCHARGES.

MONROE GEORGE WOOLFSON.

The various types of electric discharges met with in practice may, for convenience of treatment, be classified as follows:

1. The oscillatory, consisting of $\begin{cases}\text{sustained oscillations}\\\text{damped oscillations}\end{cases}$
2. The non-oscillatory, consisting of $\begin{cases}\text{the aperiodic}\\\text{the ultra-periodic}\end{cases}$

We shall limit our present discussion to the cases of the discharges produced in condensive circuits (see Fig. 1), and since in these sustained oscillations can occur only when the resistance is zero or the inductance infinite we may exclude the latter altogether. We shall, therefore, confine our attention to the damped oscillation, the aperiodic, and the ultra-periodic discharges alone.

Consider a circuit in which discharges are being produced, and let its constants comprise a resistance of R ohms, an inductance of L henrys, and a capacity of C farads. It has been shown that when $\frac{R}{2}<\sqrt{\frac{L}{C}}$ damped oscillations may arise. Furthermore, when $\frac{R}{2}=\sqrt{\frac{L}{C}}$, we have the aperiodic, and when $\frac{R}{2}>\sqrt{\frac{L}{C}}$ the ultra-periodic cases. Thus, as may be recognized by even a cursory glance, our classification is quite complete and inclusive.

In what follows we shall take for granted only a knowledge of the basic principles which underlie the theory of condenser discharges, and without further comment we may proceed.

THE DAMPED OSCILLATION.

In the elementary circuit, as shown in Fig. 1, let I' be the instantaneous value of current, E'_C the instantaneous E.M.F. across the condenser terminals, and E'_L that across the induction coil.

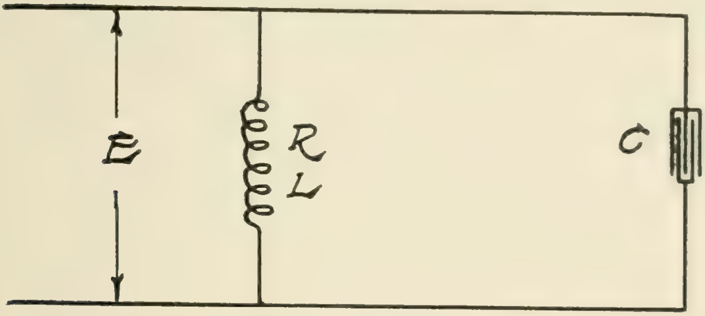


FIGURE 1

It can readily be shown that the instantaneous charge, q, at the instant t, may be represented in its most general form, as

$$q = A_1 \varepsilon^{-\beta_1 t - j\alpha_1 t} + A_2 \varepsilon^{-\beta_1 t - j\alpha_1 t}$$

in which

$$\beta_1 = \frac{R}{2L}, \qquad \alpha_1 = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}},$$

and A_1 and A_2 are constants to be determined.

According to De Moivre's theorem,

$$\varepsilon^{\pm j\theta} = \cos\theta \pm j \sin\theta,$$

whence directly

$$q = [A_1(\cos \alpha_1 t + j \sin \alpha_1 t) + A_2(\cos \alpha_1 t - j \sin \alpha_1 t)]\varepsilon^{-\beta_1 t}$$

or

$$q = [(A_1 + A_2) \cos \alpha_1 t + j(A_1 - A_2) \sin \alpha_1 t]\varepsilon^{-\beta_1 t}. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

If $q = Q$ corresponds to the time $t = 0$, we get by substitution in equation (1),

$$Q = (A_1 + A_2). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

Furthermore,

$$I' = -\frac{dq}{dt}$$

$$= -\frac{d}{dt}\{[(A_1 + A_2) \cos \alpha_1 t + j(A_1 - A_2) \sin \alpha_1 t]\varepsilon^{-\beta_1 t}\} \quad . \quad . \quad . \qquad (3)$$

$$\therefore \ -I' = -\beta_1 \varepsilon^{-\beta_1 t}[(A_1 + A_2) \cos \alpha_1 t + j(A_1 - A_2) \sin \alpha_1 t]$$
$$+ \varepsilon^{-\beta_1 t}[-\alpha_1(A_1 + A_2) \sin \alpha_1 t + j\alpha_1(A_1 - A_2) \cos \alpha_1 t].$$

$$\therefore I' = +\varepsilon^{-\beta_1 t}[+\beta_1(A_1+A_2)\cos\alpha_1 t+\beta_1 j(A_1-A_2)\sin\alpha_1 t+\alpha_1(A_1+A_2)\sin\alpha_1 t$$
$$-j\alpha_1(A_1-A_2)\cos\alpha_1 t]. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From the physical properties of the circuit it follows that at the instant $t=0$, I' is also of zero magnitude, whence,

$$+\beta_1(A_1+A_2)-j\alpha_1(A_1-A_2)=0.$$

Whence

$$(A_1-A_2)=\frac{\beta_1 Q}{j\alpha_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Inserting equations (5) and (2) in equation (4) and simplifying we get,

$$I' = -[-\beta_1\varepsilon^{-\beta_1 t}(Q\cos\alpha_1 t+j\frac{\beta_1 Q}{j\alpha_1}\sin\alpha_1 t)-\varepsilon^{-\beta_1 t}\alpha_1 Q\sin\alpha_1 t+\varepsilon^{-\beta_1 t}j\alpha_1\frac{\beta_1 Q}{j\alpha_1}\cos\alpha_1 t]$$

$$=-Q\varepsilon^{-\beta_1 t}[(-\beta_1\cos\alpha_1 t-\frac{\beta_1^2}{\alpha_1}\sin\alpha_1 t)-\alpha_1\sin\alpha_1 t+\beta_1\cos\alpha_1 t]$$

$$=Q\varepsilon^{-\beta_1 t}\left(\frac{\alpha_1^2+\beta_1^2}{\alpha_1}\right)\sin\alpha_1 t.$$

If, as in some practical cases, β_1 is negligibly small as compared with α_1, then,

$$I'=Q\varepsilon^{-\beta_1 t}\alpha_1\sin\alpha_1 t$$

and

$$I'R=QR\varepsilon^{-\beta_1 t}\alpha_1\sin\alpha_1 t.$$

Furthermore, to find the instantaneous E.M.F's. across the condenser, it need but be recalled that

$$q=E'_c C \quad \text{and also} \quad Q=EC.$$

Thus,

$$E'_c=E\varepsilon^{-\beta_1 t}[\cos\alpha_1 t+\frac{\beta_1}{\alpha_1}\sin\alpha_1 t]$$

or

$$E'_c=\frac{E}{\alpha_1}\varepsilon^{-\beta_1 t}[\alpha_1\cos\alpha_1 t+\beta_1\sin\alpha_1 t]. \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Now let us choose an angle ϕ such that

$$\phi=\tan^{-1}\frac{\alpha_1}{\beta_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and substituting in equation (6) proper values of $\cos\alpha_1 t$ and $\sin\alpha_1 t$, as deduced from equation (7) gives directly,

$$E'_c=\frac{E}{\alpha_1}\,\varepsilon^{-\beta_1 t}\sqrt{\alpha_1^2+\beta_1^2}\,(\sin\phi\cos\alpha_1 t+\cos\phi\sin\alpha_1 t)$$

$$=\frac{E}{\alpha_1\sqrt{LC}}\,\varepsilon^{-\beta_1 t}\sin(\alpha_1 t+\phi). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Reasoning similarly, on the basis that $E'_L=-L\dfrac{dI'}{dt}$, yields the expression,

$$E'_L=\frac{E}{\alpha_1\sqrt{LC}}\,\varepsilon^{-\beta_1 t}\sin(\alpha_1 t-\phi). \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Knowing now the instantaneous current and voltage values for the various parts of the circuit as stated and the phases of the E.M.F's., we may construct the vector diagram of voltages in an oscillating current circuit.

As a numerical illustration let $R=200$ ohms, $L=0.00005$ henry, and $C=0.0000000015$ farad. Suppose also that 5000 volts be the initial discharging voltage. Then,

$$\alpha_1=3{,}055{,}000;$$
$$\beta_1=2{,}000{,}000;$$
$$\phi=56^\circ\ 47';$$

whence we get

$$I'=32.23\,\varepsilon^{-\beta_1 t},$$
$$E'_L=5970\,\varepsilon^{-\beta_1 t}.$$

For various values of t as given the following results have been obtained:

t	$\beta_1 t$	$\varepsilon^{-\beta_1 t}$	$\alpha_1 t$	$\pm E'_{C,L}$	$I'R$
0	0	1	0°	5970	6546
.0000002	0.4	.670	35.01°	4001	4386
4	0.8	.449	70.01°	2680	2939
6	1.2	.301	105.03°	1797	1970
8	1.6	.202	139.9°	1206	1322
.000001	2.0	.135	175.1°	806	884
12	2.4	.0907	210.1°	542	594
14	2.8	.0608	245.02°	363	398
16	3.2	.0408	279.7°	244	267
18	3.6	.0273	315.09°	163	179
.000002	4.0	.0183	350.1°	109	120
22	4.4	.0123	385.0°	73	81
24	4.8	.0082	420.0°	49	54

From the preceding data the vector diagram accompanying (Fig. 2) has been plotted. It will be noted that the phase of I has been chosen as the datum.

The solid lines represent, to scale, the voltage and current conditions at the instant when discharge commences, i.e., when $t=0$. Here, as shown in the table, $E'_C=+5970$, $E'_L=-5970$, and $I'R=6545$ volts. Furthermore, E'_L lags behind, and E'_C leads the instantaneous current by an angle ϕ. At the instant 0.0000002 second later, the vector voltages have each advanced through an angle $\alpha_1 t$, or 35.01°, and are represented in magnitude and properly displaced by the broken lines of Fig. 2. Similarly, other radius vectors have been plotted and the loci of their heads are the spirals of the vector diagram.

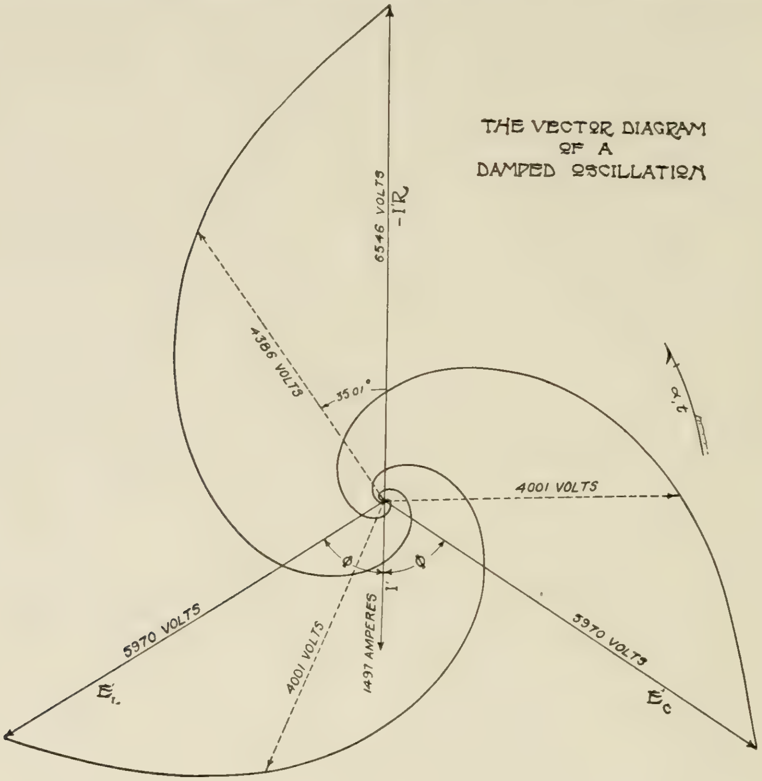


FIGURE 2

The Aperiodic Discharge.

As was suggested in the introductory statement the necessary and sufficient condition for the aperiodic discharge is that half the resistance shall equal the surge impedance, or that

$$\frac{R}{2}=\sqrt{\frac{L}{C}}$$

and as a direct consequence, that $\alpha_1=0$.

The application of these special limitations does not in any way affect the theory of the general equations of the circuit as hereinbefore advanced, but merely modifies the results thereof. Thus, for the aperiodic discharge the current assumes the indeterminate form,

$$I'=CE\varepsilon^{-\beta_1 t}\left(\frac{\alpha_1^2+\beta_1^2}{\alpha_1}\right)\sin\alpha_1 t.$$

In order that this may be evaluated we must expand the term $\sin\alpha_1 t$ into its equivalent series. Performing the indicated operation and simplifying, we get,

$$I'=CE\varepsilon^{-\beta_1 t}\beta_1^2\left(t+\frac{\alpha_1^2 t^3}{\underline{|3}}+\frac{\alpha_1^4 t^5}{\underline{|5}}+\frac{\alpha_1^6 t^7}{\underline{|7}}+\ldots\right)$$

and since $\alpha_1=0$,

$$I'=CE\varepsilon^{-\beta_1 t}\beta_1^2 t=\frac{E}{L}t\varepsilon^{-\beta_1 t}, \qquad \ldots\ldots\ldots\ldots \quad (10)$$

and

$$I'R=\frac{REt}{L}\varepsilon^{-\beta_1 t},$$

by substituting its proper value for β_1^2. This furnishes the instantaneous current value sought.

Furthermore,

$$E'_L=-L\frac{dI'}{dt}=-E\varepsilon^{-\beta_1 t}(1-\beta_1 t), \qquad \ldots\ldots \quad (11)$$

by the differentiation of equation (10) with respect to t, and substitution.

In addition, it follows from what has preceded that

$$E'_C=E\varepsilon^{-\beta_1 t}\left(\cos\alpha_1 t+\frac{\beta_1}{\alpha_1}\sin\alpha_1 t\right).$$

If, now, we expand $\sin\alpha_1 t$ into its series and make $\alpha_1 t=0$ it will appear that

$$E'_C=E\varepsilon^{-\beta_1 t}(1+\beta_1 t).$$

Thus it is obvious that E'_L and E'_C differ in phase by an angle π, whence the vector diagram of an aperiodic discharge is a straight line for any value of t. For this reason the vector diagram is wholly without significance, and a more efficacious means must be chosen to represent the conditions. To that end Fig. 3 shows curves of E'_L, E'_C, and $I'R$ for the several values of t, plotted to logarithmic abscissæ, and verifies incidentally the relation,

$$-I'R+E'_C-E'_L=0.$$

The circuit chosen is one in which $R=100$ ohms, $L=0.00025$ henry, $C=0.0000001$ farad, and the impressed voltage $E=500$. Then, $\beta_1=200{,}000$ and

$$I=2{,}000{,}000t\,\varepsilon^{-200000t}.$$

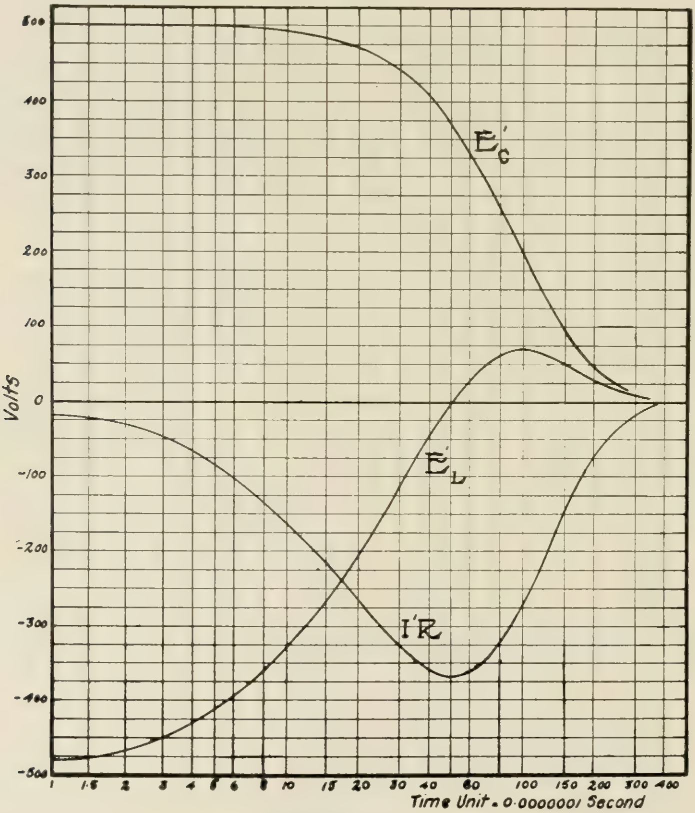


FIGURE 3

The curves of Fig. 3 have been plotted from the following figures:

t	$\beta_1 t$	$I'R$	$1+\beta_1 t$	E'_C	$1-\beta_1 t$	E'_L
.0000001	0.02	− 19.6	1.02	+499.8	+ .98	−480.2
5	0.1	− 90.5	1.1	+497.8	+ .90	−407.3
.000001	0.2	−163.8	1.2	+491.4	+ .80	−327.6
2	0.4	−268	1.4	+469.0	+ .60	−201.0
4	0.8	−359.2	1.8	+404.1	+ .20	− 44.9
5	1.0	−368	2.0	+368.0	±0	±0
6	1.2	−361.2	2.2	+331.1	− .20	+ 30.1
8	1.6	−323.2	2.6	+262.6	− .60	+ 60.6
.00001	2.0	−270	3.0	+202.5	−1.0	+ 67.5
2	4.0	− 73.2	5.0	+ 66.4	−3.0	+ 27.5
3	6.0	− 14.9	7.0	+ 45.7	−5.0	+ 6.2
4	8.0	− 2.68	9.0	+ 8.68	−7.0	

THE ULTRA PERIODIC DISCHARGE.

In concluding let us consider what changes must be made in the solutions of our general differential equations to accommodate them to the hypothesis that

$$\frac{R}{2} > \sqrt{\frac{L}{C}}$$

as before,

$$q = A_1 \varepsilon^{-\beta_1 t + \gamma_1 t} + A_2 \varepsilon^{-\beta_1 t - \gamma_1 t} \quad . \; . \; . \; . \; . \; . \; . \quad (12)$$

in which γ_1 has now been used to replace the α_1 of the original equation. If α_1 were retained it would be an imaginary quantity because of the imposed condition as above stated. Hence γ_1 is used, and is numerically equal to $\sqrt{\frac{R^2}{4L^2} - \frac{1}{LC}}$

The ultimate determination of I', E'_L, and E'_C is most readily made by an application of the hyperbolic functions, whence equation (12) shall be transformed to stand as

$$q = \varepsilon^{-\beta_1 t}[(A_1 + A_2) \cosh \gamma_1 t + (A_1 - A_2) \sinh \gamma_1 t]. \quad . \; . \; . \; . \quad (13)$$

Applying terminal conditions to find A_1 and A_2, we get

$$\left.\begin{aligned} (A_1 + A_2) &= Q \\ (A_1 - A_2) &= \frac{\beta_1}{\alpha_1} Q \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (14)$$

But $I' = -\dfrac{dq}{dt}$,

$$= \varepsilon^{-\beta_1 t}\,[\gamma_1(A_1+A_2)\sinh\gamma_1 t+\gamma_1(A_1-A_2)\cosh\gamma_1 t-\beta_1(A_1+A_2)\cosh\gamma_1 t$$
$$-\beta_1(A_1-A_2)\sinh\gamma_1 t],$$

and inserting the values indicated by the equations of set (14) gives

$$I' = Q\varepsilon^{-\beta_1 t}\left(\frac{\beta_1{}^2-\gamma_1{}^2}{\gamma_1}\right)\sinh\gamma_1 t,$$

after reduction.

Because of the inherent nature of $\sinh\gamma_1 t$, I' is non-oscillatory. Also

$$E'_C C = q,$$

or

$$E'_C = E\varepsilon^{-\beta_1 t}(\cosh\gamma_1 t+\frac{\beta_1}{\gamma_1}\sinh\gamma_1 t) \quad . \quad . \quad . \quad . \quad . \quad (15)$$

by substitution in equation (13), and similarly,

$$E'_L = -E\varepsilon^{-\beta_1 t}\,(\cosh\gamma_1 t-\frac{\beta_1}{\gamma_1}\sinh\gamma_1 t) \quad . \quad . \quad . \quad . \quad (16)$$

Suppose we take an angle ψ such that

$$\tan\psi = \frac{\gamma_1}{\sqrt{\beta_1{}^2-\gamma_1{}^2}},$$

whence

$$\gamma_1 = \beta_1\sin\psi$$

and

$$\therefore\ E'_C = E\varepsilon^{-\beta_1 t}\,(\cosh\gamma_1 t-\csc\psi\sinh\gamma_1 t).$$

Let $\psi = gdu$, or the gudermanian u. Then it follows that

$$\csc\psi = \coth u = \frac{\cosh u}{\sinh u}.$$

$$\therefore\ E'_C = \frac{E\varepsilon^{-\beta_1 t}}{\sinh u}\,(\cosh\gamma_1 t\sinh u-\cosh u\sinh\gamma_1 t),$$

and by gudermanian transformations,

$$E'_C = \frac{E\varepsilon^{-\beta_1 t}}{\gamma_1}\sqrt{\beta_1{}^2-\gamma_1{}^2}\,\sinh\,(\gamma_1 t+gd^{-1}\psi), \quad . \quad . \quad . \quad . \quad (17)$$

and in precisely analogous fashion it can be shown that

$$E'_L = \frac{E\varepsilon^{-\beta_1 t}}{\gamma_1}\sqrt{\beta_1{}^2-\gamma_1{}^2}\,\sinh\,(\gamma_1 t-gd^{-1}\psi). \quad . \quad . \quad . \quad . \quad (18)$$

We can apply equations in I', E'_L, and E'_C to obtain the numerical values necessary for the construction of the vector diagram of the ultra-periodic discharge. As a typical illustrative example consider the circuit in which $R=400$ ohms, $L=0.00005$ henry, and $C=0.000000002$ farad. Let $E=1000$ volts. Then

$$\beta_1=4{,}000{,}000;$$
$$\gamma_1=2{,}449{,}000;$$
$$\psi=\sin^{-1}.6113=37^\circ\ 41',$$

and

$$gd^{-1}\psi=40^\circ\ 44.5'.$$

Furthermore,

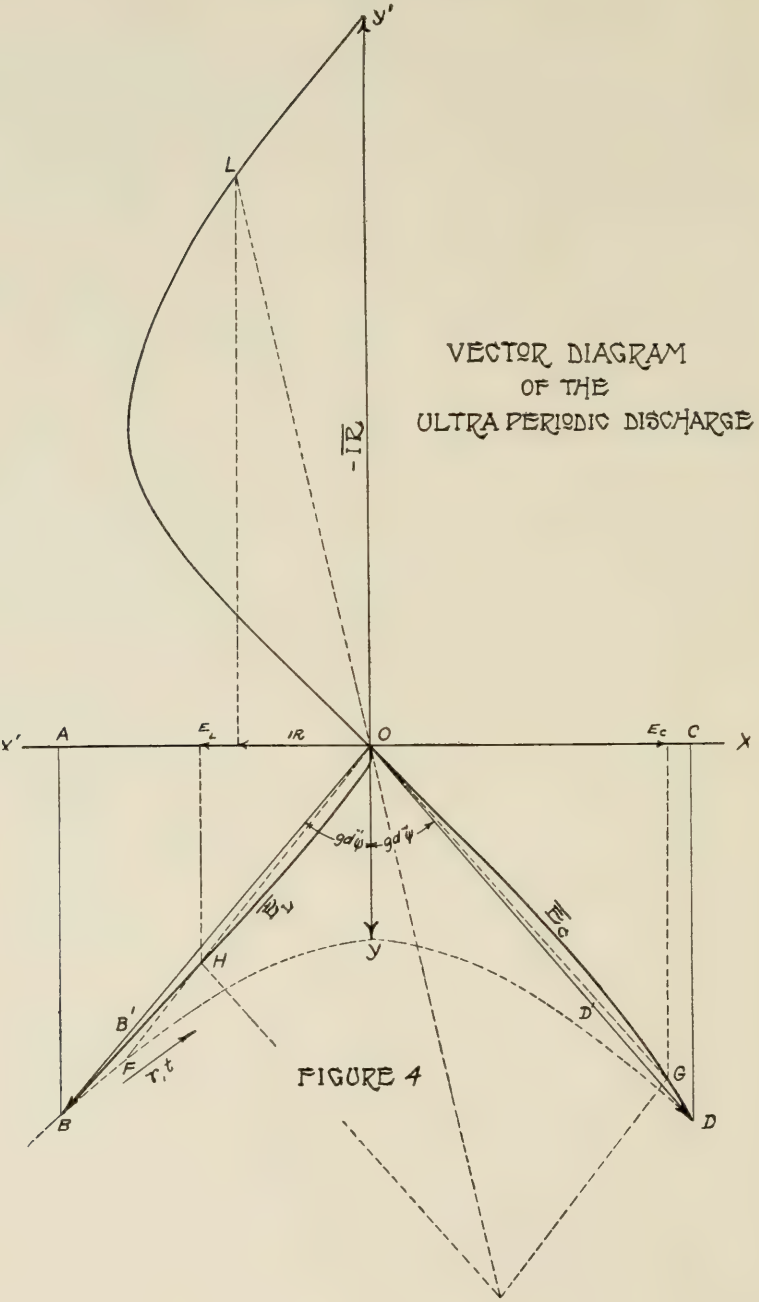
$$I'=8.166\varepsilon^{-\beta_1 t}\sinh\gamma_1 t,$$
$$E'=1290\varepsilon^{-\beta_1 t}\sinh(\gamma_1 t-gd^{-1}\psi).$$

The equations immediately above may be used to determine the numerical values of E'_C, E'_L, and $I'R$. As in the case of the aperiodic discharge it becomes apparent that $-I'R=E'_C-E'_L$. This may be seen from the data herewith given, and deduced from the circuit as stated:

t	$-\beta_1 t$	$\varepsilon^{-\beta_1 t}$	$-I'R$	E'_L	E'_C
0	0	1	0	−1000	+1000
.0000001	0.4	.670	412.0	− 551.2	962.8
2	0.8	.449	763.6	− 123.8	887.8
3	1.2	.301	803.2	+ 18.0	782.8
4	1.6	.202	774.8	+ 78.9	689 3

These figures represent the numeric values of the circuit voltages at several instants of time. They are used in constructing the vector diagram as follows:

On the horizontal axis $X'OX$, E'_L, IR, and E'_C, as given in the table, are laid off to some convenient scale. These are shown for $t=0$, as OA, O, or zero, and OC respectively. The heavy lines OB' and OD' produced, are drawn so as to make the angles $-gd^{-1}\psi$ and $+gd^{-1}\psi$ respectively with the vertical axis $Y'OY$ through the origin O. The projections OB and OD of the voltages OA and OC, respectively, on the radial lines OB' and OD' represent the vector voltages E'_L and E'_C at the instant $t=0$, and their vector sum $-I'R$, is the IR component for the corresponding time.



VECTOR DIAGRAM OF THE ULTRA PERIODIC DISCHARGE

FIGURE 4

Through the points B, D, and the head of the current vector OY, drawn to current scale, the ratio of OC to OY being made equal to the surge impedance, a rectangular hyperbola (eccentricity $= \sqrt{2}$) is constructed. This is shown as the broken line through B, Y, and D in Fig. 4.

To plot a second point lay off the values E_L, IR, and E_C as given in the table. Through O draw the lines OF and OG, making the hyperbolic angles BOF and DOG or $\gamma_1 t$ with the vectors OB and OD respectively. The projections of E_L and E_C, viz., OH and OG, on these are the voltage vectors E'_L and E'_C at the instant t. Their vector sum will equal OL, and if properly drawn L will lie in the vertical line passing through the end of IR.

Thus the vector diagram, Fig. 4, has been constructed. The heavy curves are the loci of the termini of the voltage vectors at successive instants of time.

Science is certainty, is truth found out.

—COWLES.

SENIOR INSPECTION TRIP.

JOHN H. HÜSING.

A party of Seniors, accompanied by Professor Hammond, left Brooklyn, March 5, for a trip to various engineering points of interest in Pennsylvania. A stop was made at Wayne Junction, and the Queen Lane Filter Plant inspected. This plant is composed of forty preliminary filter beds, twenty-two final or slow sand filters, a clear water basin and reservoirs for storing the water before filtration. The water to be filtered is pumped from the Schuylkill River by the Queen Lane Pumping Station through two 48-inch cast-iron pipes to the reservoir at the Queen Lane Filter Plant. Here it is allowed to settle for about three days, thereby removing much of the suspended matter. From this reservoir, the water is allowed to flow on to the rapid-filter beds, thence to the slow-sand filters and through these to the clear water basin. The rapid filters are each 32 by 40 feet and are located partly on the original reservoir site and partly on fill in two rows, being separated by a power house and office building. The supply of water and the supply of air and wash water is controlled at a small table situated in the pipe gallery between the beds. When the loss of head, due to the clogging of the beds, becomes 4 feet or more, the beds are cleaned. This is accomplished by means of an air supply at 3 to 4 pounds pressure flowing, from numerous nozzles, through the bed for three minutes, followed by a flow of wash water for about the same length of time. If the bed is very badly clogged, several repetitions of both processes are made. The wash water is supplied through large cast-iron pipes leading from tanks on the roof to small nozzles in the bed. By this arrangement the water pressure is kept fairly constant. Sheet-iron troughs are placed in every bed, about 18 inches from the sand surface, to convey the excess wash water from the bed. These filter beds are in concrete buildings heated by steam.

The slow sand filters, 344 feet 5 inches by 96 feet are in low buildings, separated by a long narrow court, and are built directly over the clear water basin. These beds are cleaned by washing the top layers of sand by means of portable ejectors or patented sand washers. Sometimes a bed is drained, and the hard layer of sediment, resting on the sand, broken up with rakes and then washed off by means of wash water supplied by an inlet level with the top of the sand. When this water is clear after flowing off filtration is resumed.

The filtering material consists of a layer of gravel 16 inches deep, composed of stones varying from 3 inches to about 1/16 of an inch in diameter. Over this is a bed of sand 20 inches in depth.

The filtered water basin occupies the entire space below the final filters and is filled to a depth of about 9 feet, being 1056 feet long and 709 feet wide, and has a capacity of 50,000,000 gallons, enough for about two-thirds of a day's supply for the district.

The total capacity of the plant is 70,000,000 gallons per day, but is now running at only 49,000,000 gallons per day. The power for operating this plant is supplied by steam engines driving two centrifugal pumps of 50,000,000 gallons per day capacity, and two large air compressors.

The buildings of this plant are of a design very pleasing to the eye, and appeared as if beauty as well as efficiency had been considered when the plant was constructed.

From here, the party journeyed to the Queen Lane Pumping Station situated near the Schuylkill River, whence it takes its supply. The plant is equipped with four Southwark vertical tripple expansion pumps of twenty million gallons daily capacity. The pumps take the river water from a wet well 32 feet deep and pump it to the Queen Lane Filters through two 48-inch cast-iron mains.

A short stop was made at the Fairmont Pumping Station, and an examination made of some of the old pumping machinery, composed partly of wood.

Then the party went to the University of Pennsylvania and inspected the various testing laboratories.

The day following was spent by a visit to the Bethlehem Steel Mills at South Bethlehem. Here, the various processes in the manufacture of steel were clearly seen, beginning with the iron ore, and leading up to the finished machinery. The first apparatus examined was the Bessemer converters. These are huge barrel-shaped containers provided with pivots on their horizontal axes, so that they can be tilted to empty their contents of molten metal. The melted iron from the blast furnaces is brought to these converters in huge ladles, about 10 feet high and about the same in diameter at the top, on flat cars. These ladles are lifted by means of a large crane to a platform, on a level with the horizontal axis of the converter. The converter is then tilted slightly, and the buckets containing the melted iron are brought into a position directly in front of the converter, and the molten metal poured into the latter. After this operation the converter is returned to its vertical position and a blast of air blown through the molten mass of metal. This removes a large amount of the impurities, but not the phosphorus. After this blast has continued for some time, an operator with a spectroscope looks at the issuing flame and if it be rich in iron, knows that most of the impurities have been burned out and that the iron is now as pure as the converter can make it. The blast of air is shut off, and the converter tilted that the contained mass may flow into a bucket on a flat car. This car brings the bucket to the open-hearth furnaces. A crane lifts the bucket from the car, another electric traveler brings a massive trough and slides it part way into the furnace, the door having been opened by an hydraulic jack. The crane, carrying the bucket with the molten metal, brings the bucket directly over the trough mentioned before, tilts it, and the contents flow into the furnace. As soon as the bucket is empty, it is returned to the flat car, the electric traveler removes the trough and the door of the furnace closes again. The men attending the furnaces are equipped with blue glasses, through which it is possible to look into the furnace, without an eye pain. Some pieces of manganese were then thrown into the furnace to improve the quality of the steel. Shortly after this, a small mould was filled with this molten metal, cooled in water, and the test specimen broken by sledges, on an anvil. The interior of this broken specimen was examined by a foreman, who could tell by the fiber structure whether the metal was ready for casting, or needed further heating. The sample broken satisfied his judgment, so several men took a long steel bar, about an inch square, and pushed it through the open furnace door, till it touched the back wall. They then rammed it back and forth until the back wall had been broken, allowing the molten metal to flow out and into a ladle previously placed on a floor below. When the furnace had been emptied, which filled the bucket to overflowing, the latter was lifted by a crane and carried to a position over some upright moulds, standing on massive iron plates, on flat cars. These moulds are open at the top and bottom, and have a slight taper, so that they can be removed by lifting upward. When the bucket was in position, a valve in the bottom was opened and the molten metal allowed to flow into the moulds. After this metal has cooled slightly, the moulds are removed, and the ingots still hot are carried on the flat cars to the "soaking pits." Here they are lifted by a movable jaw device on a crane to some low furnaces where they are stood upright, and heated to a uniform heat throughout. After attaining almost white heat, they are removed by the same movable jaws to a tilting receptacle. They are placed upright in this receptacle, and are then slowly tilted till they slide out on a platform of moving rollers. These rollers carry the hot ingots to the massive rollers which form them into I beams, rails, or blooms as the case may be. It takes numerous journeys between these massive rollers to form the finished beam or rail, each passage making the ingot a little smaller in cross section, and a little longer. After the beam or rail has been rolled to the desired cross section, it is carried along on a series of small rollers to a large circular saw, where it is cut up into desired lengths. Some of the angles coming from the rolls are over 130 feet long, but this length could not be readily transported. The famous "Gray" mill is situated in this plant, where 30-inch I beams are rolled. After the beams or rails are sawed into proper lengths, they are allowed to cool on a level platform composed of steel beams, set about 3 feet apart. Near this mill is the stock yard, where piles of beams and angles of all sizes and shapes are stored previous to shipment. The buildings just described compose the Saucon Plant.

At the other end of the stock yard is situated an immense traveling crane, so large that at first glance it looks like a steel bridge. This is used to move coal, iron ore, and other materials.

Nearby is located the immense machine shops and forging plants. Here were seen large and small cannon in all stages of construction, from the rough forging to the completed disappearing gun with breech block in place. Large traveling cranes, overhead, are used to move all heavy pieces from one part of the shop to the other. The large lathes for boring and rifling the 12- and 14-inch cannon were very interesting, the latter process being done by means of tools set on the end of a long shaft, which is slowly moved into the barrel, at the same time receiving a twisting motion, corresponding to the desired rifling, the gun being all the while stationary.

Not far from here is the crucible house, where the best tool steel and projectiles are made. Small barrel-shaped crucibles about a foot high, made of plumbago and German clay are filled with a carefully weighed charge of material to be melted, and, after being covered with small discs, are placed in long, low furnaces, the tops of which form a platform, on which the attendants work. After having been sufficiently heated, these crucibles are removed by means of hand tongs and placed on the floor. Another workman, with tongs having two small wheels on the bottom, picks up the white-hot crucible and rolls it to a large ladle, where a third attendant lifts it with another pair of tongs and pours the molten contents thereinto. After all of the small crucibles have been emptied, the large ladle is lifted by a traveling crane, carried to some previously heated moulds, and the latter filled.

Nearby are situated the tall, chimney-like structures, the blast furnaces. The coal, iron ore, and other materials are hoisted to the tops of them in cars, and poured in. The whole mass becomes highly heated and the molten iron, being the heaviest, flows to the bottom, whence it is drawn off, at frequent intervals, into channels, built in the floor, which lead to large containers on flat cars below. From here they are taken to the pig-iron moulds, and poured. The latter, situated on an endless chain ascend an incline, after being filled, and empty their contents into a chute, under a stream of water, to cool them, whence they fall to freight cars below.

Close to the blast furnaces is located the power plant, wherein numerous massive gas engines utilize the waste gases from the former, and generate electric power and drive air compressors of very large capacity.

Thursday evening a short visit was made to the Fritz Laboratory and the equipment examined. The latter consists of numerous testing machines, one of 800,000 pounds capacity, and of a size suitable for testing long beams in compression; a cement testing room, containing a Smith hand mixer; an hydraulic testing department, consisting of a water turbine, hydraulic ram, pressure tank, weir plates, and weighing apparatus. A large traveling crane overhead was used to install the machinery, and to handle heavy specimens, to be tested in the large machine.

Friday morning was spent by a visit to the Nazareth Cement Mill, situated about half an hour's ride, by trolley, from South Bethlehem. Here the manufacture of cement was studied, from the quarried stone to the bagging of the finished product. The rock-bearing stone is quarried just outside of the mill, crushed in a gyratory crusher, and carried by endless belt conveyors to long revolving cylinders wherein the moisture is removed. From here, the dry stone is conveyed to a ball-mill and ground till it passes a 20-mesh sieve. It then goes to a tube mill and is ground to a powder. A conveyor then takes this ground material to the higher end of the huge revolving kilns. The latter consist of cylinders, about 10 feet in diameter and 120 feet long. These are set on inclined rollers and have a slope of $3/8$ of an inch to the foot. They are each driven by a separate motor, and their speed is so adjusted that it takes 2 hours for the cement to pass from one end to the other. An air supply at six ounces pressure blows powdered coal into the lower end of these kilns, thereby furnishing the fuel which burns the cement to a clinker. This rolls out through an opening near the lower end, is cooled by air and water, dried and ground in a ball mill. The ground material is then mixed with about 2% of gypsum and again ground in a tube mill to a fine powder. Belt conveyors carry the finished product to three huge storage bins of 8000 barrels capacity each, whence it is carried by conveyors, through tunnels, to the automatic bagging machine. Each bag is supplied with a cloth valve in the lower corner, and, after being tied on top, a hollow tube is inserted in this valve, and cement allowed to flow in, until an automatic weighing device stops the flow. The filled bags are then dropped on a belt conveyor, which carries them to freight cars, in which they are packed and sent away.

The party next visited the large viaduct at Allentown. The construction of this was commenced in July, 1912, and will be completed in September of this year. It consists of nine main arches, almost semi-circular in shape, with a span length of 120 feet, and six smaller arches with a span of 52½ feet. When completed, with the approaches, the structure will be slightly over half a mile long. It is constructed of concrete throughout, heavily reinforced. The large arches are 4 feet thick and 8 feet wide at the center, and 5½ feet thick at the hip, connecting two solid piers at the center of the structure, but near the ends the latter are hollow. Steel arches are used to support the forms, and when one arch has hardened, the steel work is removed and erected at another point in the structure. Owing to the cold weather, the materials for making the concrete were heated, before mixing, by means of steam pipes circulating in and about them. The balustrade will be composed of square pillars of cement, about 8 x 8 inches on the bottom, and slightly smaller on the top. They are being cast separately, and will be bush-hammered before being put in place.

Saturday was spent by a visit to the Darrance Colliery, situated at Wilkes-Barre, Penn. The members of the party were each supplied with a safety lamp, and lowered on an open car to a depth of slightly over 600 feet. This was the bottom of this particular shaft, and the party then explored the various galleries, including the 15,000 gallons capacity pumping plant, which pumps against a head of over 600 feet. The party returned to the surface, after examining the Hillman Vein, about 9 feet thick, and descended an adjoining shaft to a depth of 1970 feet. A journey was taken through the numerous galleries to a heading, where the Red Ash Vein was examined. The coal is removed by blasting with gun powder, and the large pieces broken by means of picks, loaded on cars and hauled to the shaft. After returning to the surface, the party visited the breaker. Here the massive rollers are located which break the large lumps of coal into sizes suitable for factory or household use. The coal from the mine is conveyed in cars up a long incline to the top of the breaker, where it is dumped into a hopper. From here, it falls on moving screens, which separate the small pieces and guide the larger ones to the rollers. The broken coal and the slate that may be mixed with it is then allowed to slide down an automatic picker and the two materials mechanically separated.

THE DIFFUSION OF LIGHT BY MECHANICAL MEANS.

Louis A. Rosett.

A careful study of light from its distribution curves coupled with a conception of the physiological limitations of the eye will readily show that the natural brilliancy of incandescent sources is often so great as to be undesirable because of its injurious effects on the optic nerves. The glare in any natural illuminant may be annoying in the extreme, and the cause of considerable discomfort. The only logical deduction, therefore, is that we must have some mechanical means of moderating the normal light distribution.

The only means we have at present to accomplish this is by introducing shades and reflectors which might be designated as secondary light sources. A study of the advantageous utilization of reflectors is the purpose of this article.

In the consideration of the spectrum of ordinary daylight, complications arise in the blending and distribution of the visible wave lengths, from the shortest violet ray to the longest red one. These difficulties are, in the main, due to the selective reflection and absorption of light. The illumination of a body depends directly upon the different colors of the incident ray. If the light directed toward an object is rich in the color reflected by the body, it can be safely assumed that the object will be amply illuminated. If, however, the transmitted light is deficient in wave lengths of this particular color, the body will be insufficiently illuminated, and will present a dull appearance.

There are numerous artificial lights on the market to-day which possess a high intrinsic brilliancy, and are so efficient as to be extremely economical from a pecuniary standpoint. The want of quality and color value in an illuminant for distinct commercial purposes, must of necessity be our primary consideration. Innumerable appliances involving the employment of colored shades have been contrived to soften the light from artificial sources. The inefficiency of many of these inventions may be traced to the fact that the light output intensity is invariably lessened in certain parts of the spectrum. The basic principle which compels this inefficiency is that a light transmitting shade cannot color the light which shines through it. Certain wavelengths must naturally be emitted, but this invariably occurs at the expense of others. Consider, for example, a red-colored shade enveloping a highly efficient illuminant, and suppose that green rays are given off by the latter. Assuredly this shade will in a measure slightly obviate the glare, but it will also considerably decrease the light efficiency. All the wave lengths except those in the red and blue portions of the spectrum will be eliminated, because it is impossible for the shade to infuse into the radiated light that which is not already present. One distinctly important phase of our reflector question would, therefore, evince the fact that the light source should be provided with a reflector capable of blending into the illuminant the particular rays of the spectrum in which the lamp is itself deficient. The fundamental aspects of this problem lie in the consideration of the various types of reflectors, and of their adoption as essential factors to a light source in aiding the latter to give satisfactory illumination.

An electric incandescent filament with a clear glass bulb, and devoid of any reflector or globe, will radiate its light principally toward the side walls. Very little light will be directed downward, and yet this, for ordinary purposes, should be its primary direction. A test made with a sixteen candle power lamp under these conditions showed that its illuminative efficiency downward was approximately 41%. On the other hand, after this lamp had been frosted, the emitted light in a downward direction had an efficiency of 56%. The composite amount of light ordinarily given out by the lamp was reduced, and 10% absorption loss was suffered. Hence, although frosted glass presents to us the problem of a light leakage, its advantage over the clear glass lies in its high efficiency factor at the point where the light is most needed. Other considerations in favor of the frosted bulb are its more artistic appearance, and the fact that it has its filament hidden. The bare filament creates an uncomfortable glare, and when exposed, has an injurious effect on the eye. The loss of lamp life due to frosting, however, is about 50%, and from an economical standpoint it is often inadvisable to use frosted bulbs. At this point we are led to consider another modern method of diffusing light,—the globe or reflector.

The fluted opal cone reflector combines extremely high efficiency with low cost. The denser the glass, the less is light energy absorbed and consequently the more light is reflected downward; and an additional feature is, that light can penetrate the shade for keeping the side walls and ceilings illuminated. This type of reflector produces a tip candle power of twenty-three and six-tenths, while a lamp without this reflector would yield seven candle power at its tip. Lights are generally in a pendant position, and generally somewhere on the ceiling of a room, so that the importance of a ray of light directed downward is obvious. The walls and ceiling of a room are in themselves reflectors and diffusers of light, and for this reason it is evident that maximum reflector efficiency is a direct function of the proximity of the reflector to its light source. Unless light is turned away from the walls of a room, and directed toward the objective illuminative center, the light will be reflected from wall to wall, and much will be lost by absorption before it reaches the desired point which it was primarily intended to illuminate.

The flat opal reflector is a type chiefly designed to light large areas, and not to concentrate on particular points, while the green coated opal desk shade is designed for a maximum tip candle power. It concentrates the light on the desk, and allows little or none to reach the eyes; and although it does produce streaked light, this defect is very easily remedied by using a frosted globe as a light source.

Prismatic glass reflectors are manufactured with the idea that the right-angled prism is a total reflector of light, and also possesses high refractive powers. Their almost universal use is probably because through them a great downward light distribution may be secured, and yet enough light still be present to diffuse through the sides of the reflector to illuminate the side walls and ceilings. There are three types of prismatic reflectors,—focusing, extensive, and intensive. Prismatic reflectors have even been designed to give asymmetric distribution of light for both desk and window lighting.

In alternating current arc lamps, a reflector is almost indispensable to procure any illuminative efficiency. In many cases, chiefly for outdoor work, a flat white disk, small enough to be inclosed within the outer globe, is used. Cone-shaped metal reflectors enameled on the under sides also find favor in practical illumination. A particularly effective arc lamp reflector, which is used exclusively for interior illumination, is the concentric diffuser. This type has an inner globe of clear glass, surrounded by an outer opal one, which is well suited for reflecting downward the major portion of the light. Above the arc is a round diffusing reflector with concentric ridges spread over the whole of its surface and covered with white enamel, whose reflection coefficient is large.

Cooper Hewitt Lamp.
Direct Current, Type P.

There are numerous and varied types of reflectors, among them the opal dome reflector, which produces a great tip candle power. The prismatic bowl and the parabolic reflectors reflect parallel light rays from light sources at their foci. The opal dome reflector is particularly adapted for the illumination of a dining-room table, and might also be used on chandeliers in various kinds of rooms. This type of reflector is also made use of in portable table lamps because it tends to throw the light beyond the edges of the table. The prismatic bowl reflector is most widely used when a very strong light is desired. The parabolic reflector is employed mainly in automobile lamps, search lights, and locomotive head-lights. There is also the McCreery desk shade with the ground glass bottom to eliminate streaked light, and also the Holophane corrugated mirror reflector which produces a large tip candle power.

There are really so many different kinds of reflectors that this article must restrict itself to the more important types. No discussion of reflectors is complete, however, without a reference to one of the most ingenious special reflecting devices,—The Cooper Hewitt Reflector,—which is desined to meet the peculiar qualifications of The Cooper Hewitt mercury vapor lamps. This reflector's underlying idea is the principle of fluorescence. A light-radiating source which has a deficient and poorly balanced spectrum is thereby transformed into one of an entirely different set of wave lengths. The radiant energy is converted by the peculiar molecular character of the fluorescent material, and this organic substance acts in co-operation with the emitted light from the primary source. The fluorescent material gives forth its own wave lengths, and these, in combination with the original colors from the illuminative center under consideration, cure the latter's deficiencies. The reflector may be truly termed a light-transforming device. It consists of a reflecting surface of kalsomine which emits a diffused reflection, and, covering this substance, a thick coating of a translucent, fluorescent dyestuff. This compound is usually Rhodamine B, a coal-tar product. The reflector is put directly in back of a light source, and the radiant energy of the emitted wave fronts of light is changed in passing through the fluorescent dye to the light-scattering and light-reflecting surface; this, in turn, gives out a number of wave lengths in the lower band of the spectrum. These waves are the short red- and orange-colored ones. A composite highly efficient lighting unit is thus obtained, possessing all the necessary colors, and offering a better distribution efficiency than the one obtained by the light source alone or by the illuminative unit with an ordinary non-fluorescent shade or reflector.

Cooper Hewitt Lamp.
Alternating Current, Type F.

This idea of a well-balanced spectrum takes us into the field of the spectrum of ordinary daylight. All sorts of lamps are designed to produce light when daylight fails us. When the study of fluorescent reflectors has been exhausted, it can safely be assumed that a means of artificial illumination will have been invented which will compare favorably with the natural light of day. It will also be found that the spectrum of the resultant artificial light will bear a close resemblance to the spectrum of daylight.

The rules and formulas for the use of illuminative units and their reflectors are many, and a reflector that would give excellent results in one case, would hardly be practicable in another. Common sense, good judgment, and an appreciation of the beautiful, all are qualities which should accompany adequate engineering knowledge of the problem at hand. Every reflector has its bad points; and, to secure efficiency in a reflector, the good qualities must outbalance the bad. When it can be said that a certain reflector is beautiful, inexpensive, and, above all, efficient, it has reached the state of perfection which is requisite for its utility.

Dark with excessive light.

—MILTON.

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BLUE AND IRIDESCENT GELATINE-COPPER.

FREDERICK W. MOE, JR.

Great as is the variety of uses copper may be put to, none is more recent than the artistic decoration by means of colored superficial films or "patinas." There is a great variety of colors which may be thus imparted to copper, but a rich and true blue patina for this metal is practically unknown. It was while seeking such a blue surface film that the electrolysis of copper acetate solutions containing gelatine was first performed.

One gram of gelatine was dissolved in 325 c.cs. of a 1% solution of copper acetate, and this mixture electrolyzed between carefully cleaned electrodes of sheet copper.

The electrolysis was continued for five minutes with a current density which was approximately 0.45 amperes per sq. dm.

The process was carried out at about 21° C.

On removing the cathode it was found to be covered on its inner surface with a thin, pale brown deposit, which, when rubbed with the fingers was found to possess a peculiar, slippery surface caused by a very appreciable amount of gelatine deposited simultaneously with the metallic copper. No gas became visible at either pole during the passage of the current. In itself, this pale brown deposit gave no indication of its peculiar properties and it was by the merest chance that these were discovered. An electrode freshly coated with a layer of the gelatine-copper was, by an oversight, allowed to remain in the solution of copper acetate from which the film of metal had just been deposited and the current was turned off. On removing the electrode from the solution, it was noticed that the brown color originally possessed by the cathode film had given place to a purplish blue of extraordinary brilliance and beauty. This led to further experiments.

A second electrode was then coated with a film of gelatine-copper and, after careful rinsing with cold tap water, immersed in a 5% solution of copper acetate containing no gelatine. Immediately there ensued a remarkable series of color changes upon the surface of the copper deposit; hues of startling evenness and intensity followed each other in regular succession until the electrodes had acquired a magnificent deep-blue coloration. This process we may speak of as a "development" since it bears a certain resemblance to the development referred to in photography.

Let us ascertain the formation and nature of gelatine-copper. It became evident that gelatine must be present in the electrolyte, and that this colloid exerted a tremendous influence upon the nature of the cathode deposit. The term gelatine-copper was thus justified. The electrolysis of copper acetate solutions containing no gelatine failed to give the developable films, nor was it possible to substitute other hydrophile colloids such as starch or gum-arabic for gelatine or glue.

Variations of the temperature and current at which the electrolysis was performed led to most interesting results. Between 20° and 40° C. and with a current of about 0.4 amperes, the cathode deposit was of the usual pale brown color and gave a more or less satisfactory color-development to blue in copper acetate.

But the color development was neither as intense nor as brilliant as the one obtained at 20° C. Lowering of the current merely delayed the operation. At about 50° C. the cathode deposit was colored a bright intense red which was unaffected by the developing solution. At about 60° C. a short electrolysis with a low current density gave a gold colored but very thin film which had a rather iridescent appearance. By raising the temperature to 70° C. and lowering the current with a water rheostat, so that almost no current flowed, a very good combination of these colors was obtained.

We will now discuss the theory. The gelatine acts as a "protecting colloid," migrates by cataphoresis to the cathode, and there inhibits the growth or crystallization of the copper nuclei. Gelatine-copper is an irreversible gel of colloidal copper. The whole phenomenon is but an example of the marked influence of organic and other colloidal substances upon metals prepared by electrolysis.

The blue, although a superficial color, is nevertheless not the color of the thin film of gelatine or oxide bringing about interference or disturbances in the reflected rays of light. Nor does it seem to be the color of a definite chemical compound. The blue layer does contain oxide, as is shown by its action in hydrazine, and yet it cannot be prepared by any process of simple oxidation. It cannot be produced by the partial coagulation of the copper-gel.

The color changes that appear on the film are the result of a surface absorption of hydrous copper oxide from the copper solution. The hydrous copper oxide is present as a suspension in very appreciable quantities in the acetate solution. being the product of hydrolytic dissociation.

In conclusion it can be said in support of this hypothesis that it is in accord with many of the established facts in colloid chemistry and explains in the best possible manner this decidedly obscure phenomenon.

By fire
Of sooty coal th' empiric chemist . . .

—MILTON.

THE PITOT TUBE.

H. P. HAMMOND.

This paper has for its object the brief presentation of the history, principles, and uses of the Pitot tube as applied to the measurement of the flow of water. It may be that the importance of the instrument does not warrant an historical sketch, and that its principles and uses are so well understood that no benefit will be derived from their further discussion; yet the writer's observation has led him to believe that the present use of the device is not in proportion to its merit, and that great benefit would result from its wider adoption. He feels justified, therefore, in presenting, in connected form, some of the facts relating to the subject, with the hope that he may add, thereby, to an appreciation of the merit of the instrument, and aid in its further development and adoption.

The Pitot tube bears the name of the French engineer whose use of it in 1732 is the first recorded. Pitot employed the device in endeavoring to measure the velocity of water in open channels. After Pitot used the device there is an interval of over a century until the next recorded employment appears. D'Aubisson, in his "Hydrauliques," 1858, speaks of the work of DuBuat and of Mallet with the Pitot tube. Mention is made in "Recherches Hydrauliques," 1866, of D'Arcy and Bazin in connection with investigations of the flow of water in channels in which they made use of the instrument. The work of these men was begun in 1855 by D'Arcy, and, after his death in 1858 continued for several years by Bazin. At that time the tube seems to have been regarded as an accurate measuring device, for considerable work of great value was done.

It was not until 1888 that American engineers made use of the Pitot tube. Noteworthy among these have been Freeman, 1888, in his experiments on the velocity of fire streams; Cole, 1897, in his investigation of pipe flow at Terre Haute, Indiana; Williams, Hubbell and Fenkell, 1898, in their work on the Detroit, Michigan distributing system; Judd and King in their studies of flow from standard orifices; Gregory in developing the Tulane Pitot tube; and Sanborn in determining the speed of boats. Further mention will be made later of the work of these men.

The Pitot tube is essentially a small tube or pipe bent near one end to an angle of 90°. When the short end of such a tube faces directly toward a moving liquid the liquid rises in the long end of the tube above the "free" liquid surface to a height which is a function of the velocity of the liquid impinging upon the short end of the tube. An expression for this height may be derived by considering the moving filaments of the liquid to produce a dynamic pressure upon the stationary liquid in the tube. This dynamic pressure will have the value wav^2/g; where w = the weight of a unit volume of liquid, a = the cross-sectional area of the bore of the tube at the end, v = the velocity of the liquid, g = the acceleration of gravity. This may be equated to the hydrostatic pressure at the bottom of the long leg of the tube. Then

$$wav^2/g=wah$$

$$\text{or } h=v^2/g=2v^2/2g.$$

Therefore the height, h, attained by the liquid is twice the velocity head of the moving liquid. Experiments show that a coefficient must be applied to this to make it fit the practical case; or

$$h=cv^2/2g,$$

and, theoretically, c should have a value of 2.

It is noted in the record of Pitot's use of the tube that he employed a trumpet-shaped tube and found c to be about 1.5. D'Arcy used a tube drawn to a fine point and found c to be almost precisely 1.0. This would indicate that the small opening was influenced merely by the velocity head and that dynamic pressure had no effect. Whatever the principle may be, it is a fact that when a fine-pointed tube faces directly toward a current of water the height attained above the free water surface is $v^2/2g$. Why this should be so is a matter of conjecture. In this article it will suffice to say that many experiments have shown it to be true within the limits of accuracy of the most careful observations. William White states that he has observed h to be within 0.01 of the velocity head of a jet from an orifice. (Proceedings of the Engineers' Club of Philadelphia.)

The height h is equal to $v^2/2g$ only when the tube faces directly toward the moving liquid. When it is turned at an angle to the direction of motion the height attained is less than the velocity head and may be even less than the height of the free liquid surface. The relation between the angle made by tube with the direction of motion and the height attained is illustrated by Fig. 1.

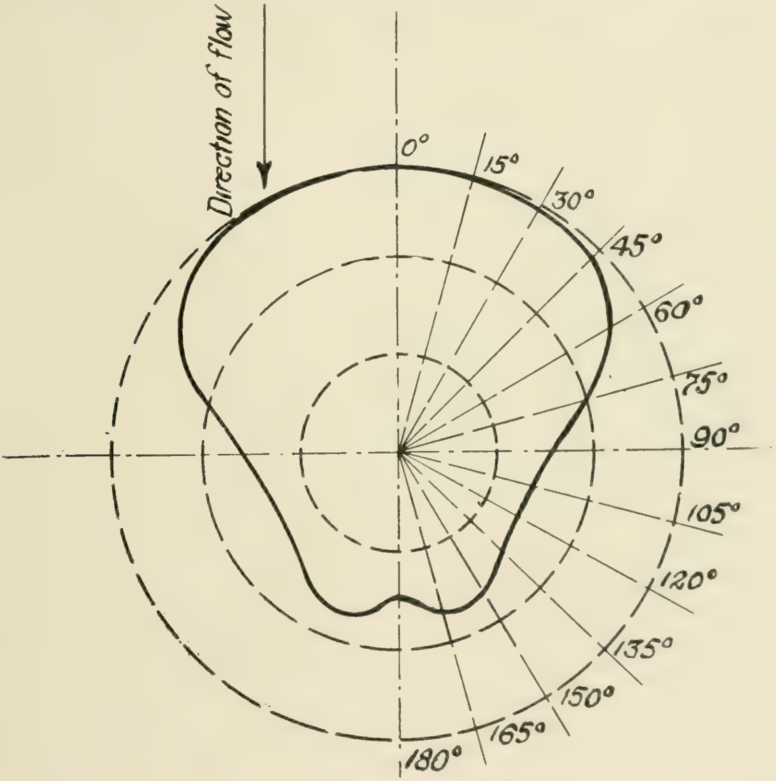

FIG. 1.

In this figure the radius of the middle circle represents, to scale, the static head h_1, that of the outer circle represents $h_1+v^2/2g$ (the sum of the static and velocity heads) and that of the inner represents

$h_1 - v^2/2g$. The pear-shaped figure is a plot of the head in the tube for each of the angular deflections shown. It is seen that the height attained is equal to the static head when the angle of deflection is about 75° and not 90° as might have been expected. The explanation of this lies probably in the fact that the liquid filaments are deflected by the walls of the tube and pass the opening at an angle instead of parallel thereto. This would tend to form a vacuum at the point and consequently a lower head than the static would result. It is also noticed that when the tube is turned to 180° the head recorded is nearly $h_1 - v^2/2g$. The shape of this figure cannot be regarded as accurate or as applying to all forms of tube, but is typical and serves to illustrate one of the principles. It may be remarked that when the opening is a small hole in a relatively large surface, the tube becomes a piezometer and when turned at an angle of 90° with the direction of flow registers accurately the static head.

The above mentioned properties of the Pitot tube render it of great value to hydraulicians and it may be safely said that in simplicity, accuracy and convenience it stands unrivaled among the devices for measuring the velocity of flowing water. Its adaptation to meet practical requirements presents considerable difficulty and it will be shown how these may be met.

The use of the Pitot tube in the field of hydraulics may be classified and will be discussed under four heads: The measurement of (1) flow in open channels, (2) flow in pipes, (3) the velocity of jets, and (4) the speed of boats.

AS USED FOR MEASURING THE FLOW IN OPEN CHANNELS.

The early experimenters directed their attention to this use of the device. Pitot, the originator, employed a tube of the form shown in Fig. 2. D'Arcy's tube had the form of which Fig. 3 shows the essentials. It is interesting to note D'Arcy's use of the tube facing directly away from the current.

A simple bent tube of glass or of metal with a glass tube near the top for noting the height of the water column, together with a suitable scale will serve to measure the velocity at any point in a stream.

The point of the tube should face the current and the height attained above the water surface noted. The velocity of the filament of water in which the end of the tube is placed can then be obtained by solving the equation $v=\sqrt{2gh}$ for v. This would be an awkward apparatus to handle, since for low velocities the height attained is small and the observer would be obliged to read the scale very close to the water surface. To avoid this, one tube may be used to record the velocity head and another to record the hydrostatic head. These may be connected to parallel tubes of glass, both heads elevated to a convenient height by suction and observations easily made. Devices similar to this have been employed with considerable success. D'Arcy placed pinchcocks at the bottom and top of his gauge. By closing these cocks when the water in the gauge was at a convenient height he could lift the apparatus from the water and make an observation with ease and accuracy. Many of the early experimenters attached the tubes to a rod which could be held firmly at any desired point in a stream. Fig. 4 is the type of tube employed by the U. S. Geological Survey Engineers in experimenting on the transporting capacity of currents.

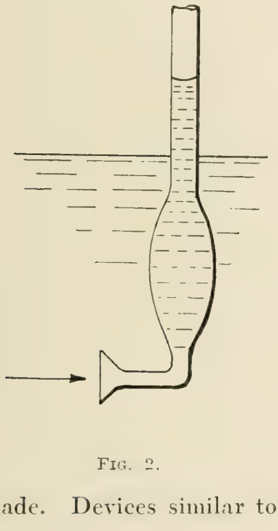

FIG. 2.

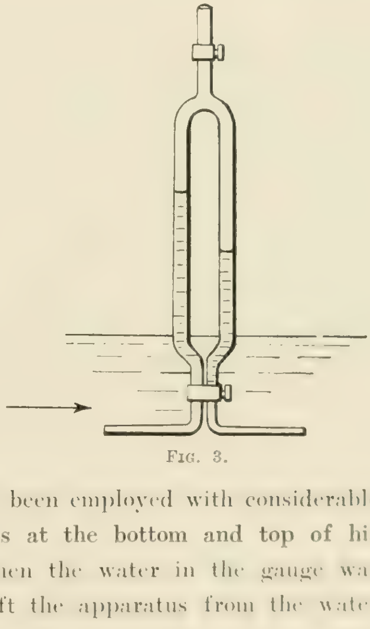

FIG. 3.

It will be noticed that the facing point is used to measure $h+v^2/2g$ and the so-called "trailing" point to measure $(h-v^2/2g)$. The trailing point has the advantage that it increases the difference in height of the water columns to be read in the glass tubes or "gauge," but has the disadvantage that it must be calibrated. The simple Pitot tube point and piezometer placed side by side give at once

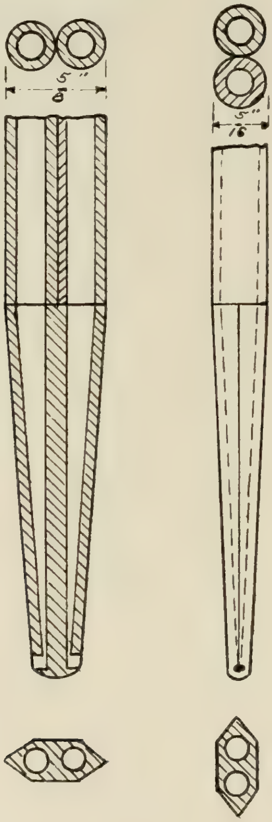

FIG. 4.

precisely the velocity head, whereas the facing and trailing points indicate a difference of head greater than this, as shown by Fig. 1, and this difference varies considerably with the type of tubes employed. A calibration is necessary, then, before the instrument employing facing and trailing points can be used to measure velocities.

A calibration is made in the same manner as for current meters, that is, the tube is attached to a boat or car and moved through still water at various velocities. A rating table or curve is then prepared or a coefficient established, to be used when the tube is employed to measure unknown velocities. This introduces two sources of error in the results—one the observational error of calibration and the other the observational error of use.

The increase in the head obtained by using the facing and trailing points is of considerable advantage in the measurement of small velocities. For example: a velocity of 1 ft. per second gives a head of but 0.0155 ft., when indicated by the Pitot tube and piezometer. This is a very short distance and a small error in reading it has a large effect on the result. If the facing and trailing points are used this head may be increased nearly two-fold.

A still greater increase may be obtained by tilting the gauge to an angle with the vertical, and noting the difference of readings in this position. For example, if the gauge is held such that it makes an angle of 15° with the horizontal a difference of 0.0155 ft. becomes $0.0155 \times$ cosecant $15^\circ = 0.060$ ft., a distance very much easier to read and introducing a much smaller error in the result. Such a device can be made very compact and convenient. A small spirit level makes it possible to keep the tube in a correct position and a protractor can be used to indicate the inclination of the gauge.

The strongest recommendations for the use of the Pitot tube for the measurement of velocities in streams or other open channels are compactness and convenience, practically equal accuracy for all ranges of velocity (a property not possessed by the ordinary current meter), the short time needed for making an observation (only enough to note and record the heights of the water columns in the two glass tubes), and the fact that it indicates the velocity of a single filament of water only. This last property renders it very valuable for determining accurately the velocity at any desired point in a cross-section and in studying the laws of the variation of these velocities.

AS USED FOR MEASURING THE FLOW IN PIPES.

This use of the Pitot tube has been more extensively developed than any other. Several successful instruments have been designed and a great deal of very valuable data on the flow of water in pipes has been collected, made possible by its use only. A few devices for measuring the flow of water in pipes by the use of Pitot tubes are being manufactured for general sale. Some of these possess considerable merit and are both convenient and accurate, but they have not as yet found the acceptance which their good qualities warrant. This development is in a large degree accounted for by the scarcity of, or almost total lack of, devices for determining the flow in pipes. The only one of wide adaptability aside from displacement and inferential water meters, is the Venturi meter. All other devices measure the water before or after its passage through the pipe, an unsatisfactory method at best and in the great majority of cases entirely inadequate. Ordinary water meters are open to two very serious objections aside from their great cost in larger sizes: first, the fact that they are not equally accurate for all velocities, indeed, that they have a certain critical velocity below which they fail to register; and second that they introduce large frictional losses of head. The Venturi meter is an excellent device—accurate for wide ranges of discharge, simple in principle and construction, and convenient to use; but it is very expensive for large sizes and difficult to install in existing pipe lines. Moreover, as a means of recording flow other than the instantaneous discharge it is dependent upon the accuracy of a recording differential gauge and for that reason is subject to the same inaccuracies as the Pitot tube. The Venturi meter does not possess the advantage of the possibility of determining velocities at numerous points in a cross-section.

Some of the most valuable contributions to our knowledge of the flow of water in pipes have been made possible by the Pitot tube. The experiments of Williams, Hubbell and Fenkell, referred to above, in connection with the flow of water in the Detroit, Michigan distributing system are noteworthy among these (Trans. Am. Soc. Civil Engineers, Vol. 47, pp.12-275). The tube employed by these men, after several had been tried, had the form shown in Fig 5.

It was introduced into the pipe through a stuffing box (See Fig. 6) arranged so that the point of the tube could occupy any desired position on a given diameter. An oil differential gauge was used for indicating differences in head. The tubes were calibrated in two ways: first, by moving them at known velocities in still water in a circumferential trough and second by "traversing" a pipe in which the velocity was accurately known. In the first case the tube was mounted on an arm so arranged that by rotating it on a central pivot the tube would describe a circumference in the water in the trough. Fixed to the arm was an oil gauge and observer's seat.

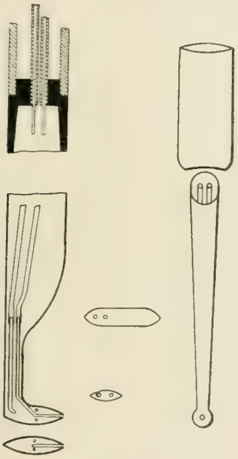

FIG. 5.

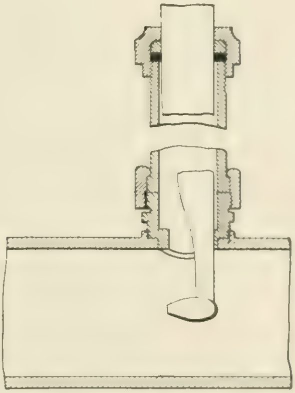

FIG. 6.

Sets of observations were made by rotating the arm at known speeds and recording the difference of head indicated by the gauge. In the second method the tube was inserted in a smooth brass pipe the actual flow in which was obtained accurately by weighing the discharged water for a definite time interval. The cross section of the pipe was divided into a central circle and concentric rings of equal area and the point of the tube placed successively in each of these as indicated by Fig. 7. Readings were taken for each position occupied and the corresponding velocity computed from the formula $v=\sqrt{2gh}$. The total discharge was then computed by multiplying each velocity by the area of the ring in which it was noted and taking the sum of the results, or by using the mean of adjacent velocities and the proper areas. The observed central velocity divided by this value gave a ratio Vc/V This ratio was found to be constant for any cross-section of a given pipe for all velocities. This is an important point, for upon it rests the convenient adaptation of the Pitot tube to use as a water meter. The tube was then placed at the center of the pipe and observations made for a wide range of velocities. The ratio of the actual mean velocity to the observed mean velocity was obtained from these results. The coefficient of a tube rated in this manner will be the ratio of mean to central velocity multiplied by the ratio of actual mean to observed mean velocity. By the use of this coefficient it is necessary only to fix the tube at the center of the pipe, observe the central velocity and multiply by the coefficient to obtain the discharge.

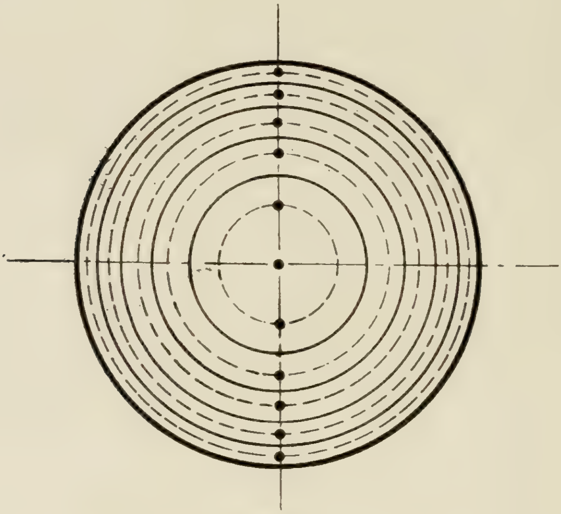

FIG. 7.

Bazin calibrated his Pitot tubes by three methods: First by attaching the tube to a boat which was then drawn through still water at known velocities, second by placing the tube in a channel the velocity of which had been obtained by means of float measurements, and third by observing velocities at numerous points in a channel the discharge of which was obtained by weir measurements.

The instrument known as the "Pitometer" was devised by Mr. Edward S. Cole to supply the need of a convenient means of measuring pipe flows in connection with his work on the Terre Haute, Indiana, distributing system. The results from the use of the instrument were so satisfactory that it was improved and is now manufactured and for sale by The Pitometer Company, New York. Fig. 8 shows the instrument set up ready for use. It consists of two Pitot tubes enclosed in a rod-like case, each tube capable of rotation about its longitudinal axis. The ends of these tubes are gripped by a collar the rotation of which turns the tubes to face in any desired direction. The upper ends of the tubes are connected by rubber tubing to a gauge. When the instrument is to be used the tips are made to face toward each other; it is then introduced into the pipe through

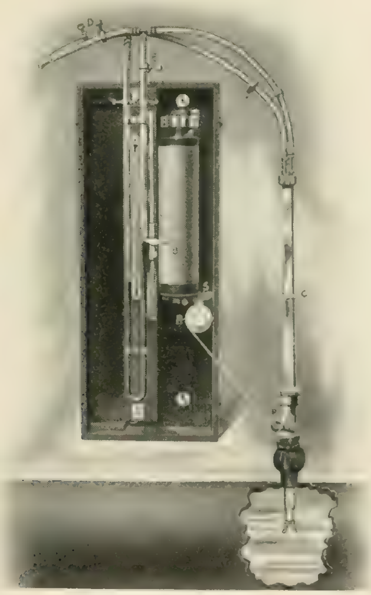

Fig. 8.

a corporation cock and the points turned so that one faces upstream and the other downstream. An indication of the velocity head at any desired point in a pipe is then obtained by the use of some form of differential pressure gauge. Mr. Cole employed a U gauge containing a mixture of colored carbon tetrachloride and benzine of a specific gravity of 1.25, though any desired specific gravity may be obtained by varying the proportion of benzine and carbon tetrachloride.

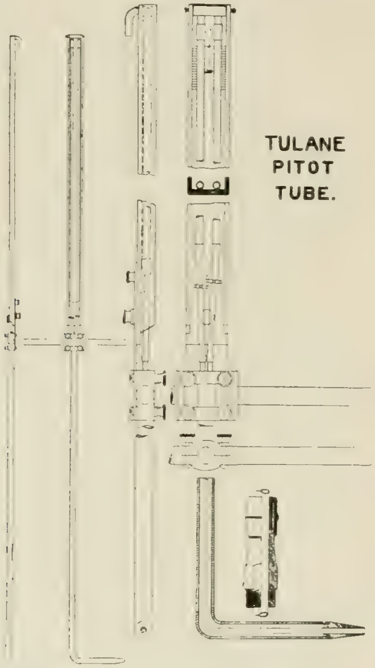

FIG. 9.

Other forms of Pitot tubes are for sale. One of the more successful is called the "Tulane Pitot tube" and was devised by Prof. Gregory of Tulane University. It is for sale by A. M. Lockett & Co., Ltd. of New Orleans. Details of the instrument are shown in Fig. 9.

Objection to many of the Pitot tubes on the market may be raised on two grounds: First, that each instrument has a "constant" factor which must be obtained by careful calibration, and second, that the rods or tubes occupy a considerable portion of the cross-section of moderate sized or small pipes and create disturbances which disarrange the normal conditions of flow.

The first objection arises from the fact that the opening used to record the static head does not record exactly that head but a smaller quantity. The objection may be met by removing the opening from the movable tube or rod and substituting for it a hole or holes drilled in the wall of the pipe. The static head will be accurately recorded by this arrangement. The "Facing Point Pitot Tube" can be used as in other instruments and with equal freedom and accuracy. There is no necessity for a calibration of each instrument for the difference in head recorded will be accurately equal to the velocity head of a filament of water in which the tube is placed. It will be necessary of course to "traverse" the cross-section of the particular pipe in which the tube is to be placed to determine the relation of mean to central velocity; that is the "Pipe Constant" must be determined but the "Instrumental Constant" is unity and no calibration is needed to determine it.

The second objection may be met by extending the point of the tube out into the moving current beyond the region of disturbance. The pressure openings in the pipe wall should lie in the same vertical plane as the tip of the tube.

The greatest difficulty in using the Pitot tube for practical purposes is in obtaining a continuous record of flow. Several ingenious devices have been designed to meet this requirement. Mr. Cole employs photography as the basis of his device. It consists of a rotating drum, revolved by clock-work, carrying a properly graduated sheet of sensitive photographic paper, and a small lamp which throws a plane of light through a refracting prism in such a manner that part of the rays are intercepted by the liquid in the gauge and part fall upon the paper. As the level of the liquid in the gauge varies, a continuous record of its elevation is left on the paper; and when this is developed, it constitutes a permanent record of the flow for any desired period. The features of this instrument may be seen by referring to Fig. 10. Considerable work of great value has been done with this device in connection with the detection and prevention of leakage and waste in city distributing systems. Fig. 11 is illustrative of this fact. It shows the reduction of waste in Washington, D. C., and is typical of what has been done elsewhere.

Another excellent device is that manufactured by the Simplex Valve and Meter Company of Philadelphia. Fig. 12 shows the "Register" gauge set up ready for use. It is similar to the device made by the same company for recording the flow through a Venturi meter.

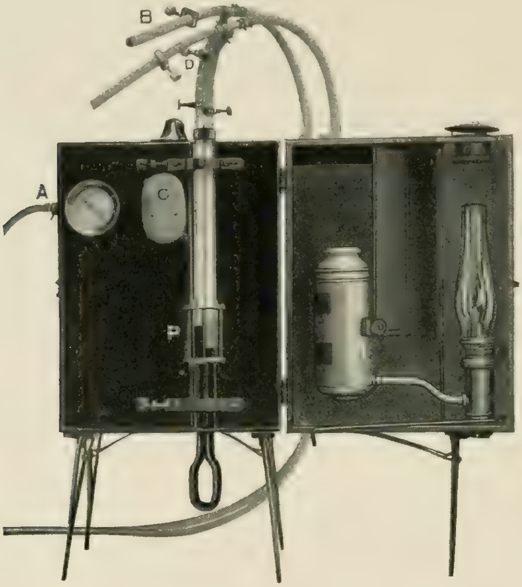

FIG. 10.

Another patented device records the flow by means of a recording differential Bourdon pressure gauge. One chamber of the gauge is connected to the "pressure point" and the other to the "trailing point." A pencil or pen is connected by suitable toothed gears and levers to the two chambers and is so arranged that it makes a mark on a sheet of paper wound about a rotating drum. This device gives good results but is not as accurate as the two previously mentioned.

These illustrations will serve to show that it is quite possible to meet the difficulty of recording the flow over any period of time.

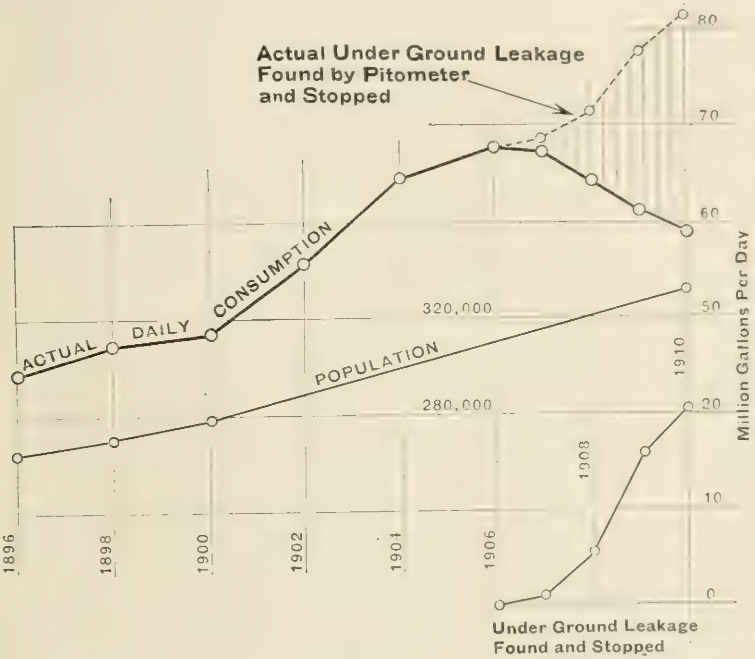

FIG. 11.

AS USED FOR MEASURING THE VELOCITY OF JETS FROM ORIFICES AND NOZZLES.

Since there is no static pressure in a jet issuing from any orifice the problem of obtaining its velocity by means of a Pitot tube is a simple one. All that is needed is the placing of the tip of the tube facing directly toward the stream. The velocity head of the filament of water impinging upon the end of the tube can then be indicated on any form of pressure gauge.

Such a device was used by Mr. John Freeman in his experiments on streams from fire nozzles and by other experimenters with results which have thrown much light on the laws of flow and the variation in filament velocities (See Trans. Am. Soc. Civil Eng. 1889. Vol. 21, p. 413).

The device employed by Mr. Freeman consists of a Pitot tube, protected by a cut-water, connected to a gauge of the Bourdon type. In using this instrument the writer has checked his observations to a small decimal of one per cent. It may be remarked that its accuracy depends only upon the gauge employed and that accurate and sensitive gauges for any range of head can be easily obtained.

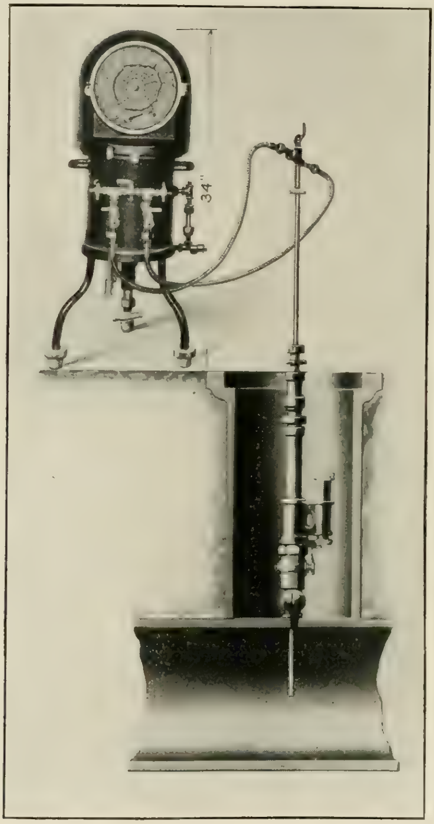

Fig. 12.

AS USED FOR MEASURING THE SPEED OF BOATS.

The Pitot tube registers the velocity of the water filament relative to the tube—hence if the water is stationary and the tube moved through it a result similar to that obtained by holding the tube stationary in moving water will be obtained. This property of the tube renders it of use in determining the velocity of boats.

A device named the "Sanborn Marine Speedometer" has recently been patented and placed on sale. It is essentially the same as Mr. Freeman's instrument and differs from it only in detail. Fig. 13 shows the tube protected from sea-weed or debris by the triangular cut-water and Fig. 14 is the gauge. The latter is of the usual Bourdon type. From the nature of the device it must be placed at a definite elevation above the water surface and this elevation must not change. In the above mentioned device this is fixed at a height of one foot above the water surface. An allowance for small changes in this difference of elevation may be made by turning an adjustment nut. Prof. Sanborn, the inventor, tested the device by timing a boat over a measured course and found it accurate to the smallest division on the scale of the gauge. The advantages of such an instrument

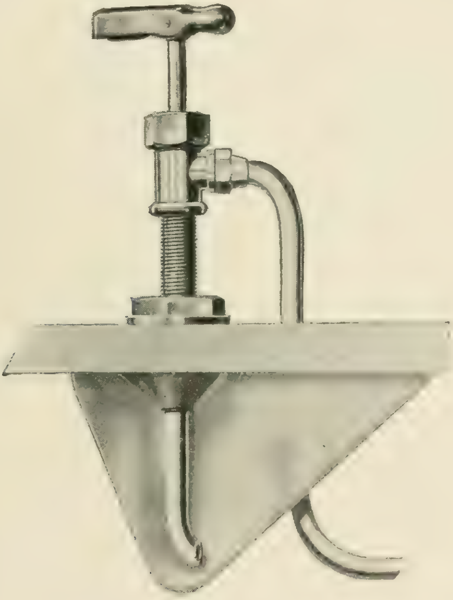

FIG. 13.

are its simplicity, cheapness, and accuracy. By its use many factors in the speed of ships may be known and corrected to obtain economical operation.

From what has been said the great variety of uses to which the Pitot tube is adaptable may be judged. Its wide range of usefulness, accuracy, simplicity, and convenience recommend it for many uses where now expensive, cumbersome, and inaccurate instruments are employed.

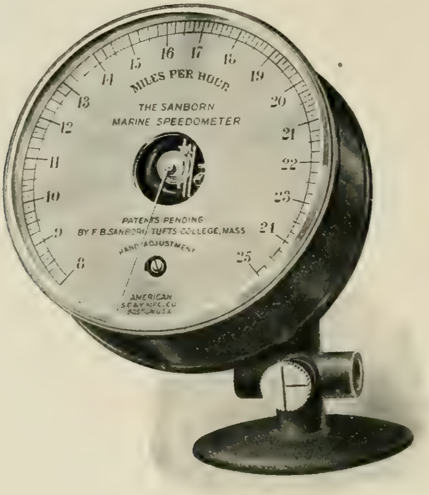

FIG. 14.

CHINESE WOOD OIL

EVERITT J. COLE.

Chinese wood oil, once a curiosity, has assumed an important position in the world's oil business and hence any information concerning it is most welcome to the chemical industry. It is almost unique in possessing the property of polymerizing and solidifying under the influence of heat, and this property is made use of as a commercial test. If the oil is heated at 280° C. for a short time, it solidifies. The rapidity with which this occurs and the hardness of the jelly are indications of its purity. A pure oil will solidify within 8 to 10 minutes. An oil with 10 per cent adulteration will solidify within 10 to 15 minutes. If this test is made parallel with a standard sample, a good qualitative notion of the purity will be obtained.

The analytical properties of the oil, as stated by various authorities, are quite varied. The reason for this is understood when the crudeness of the method of handling the oil is realized. The oil is pressed from the wood oil nuts by various individuals who sell to the middleman, who in turn ships to merchants in Hankow. Here it is clarified by settling and prepared for shipment. It is a very difficult matter to obtain a sample of absolutely guaranteed purity and known source.

The figures given by various authorities are given in Table I.

TABLE I

ANALYTICAL CONSTANTS OF CHINESE WOOD OIL.

Observer.	Specific Gravity	Saponification Number.	Acid Number.	Iodine Number
Lewkowitsch	.941–.942	—	—	163.4
Jenkins	.934–.938	192–194	—	150–165
Allen	.937–.940	266–360	—	159–165
Kreibenbaum	.941–.943	190.9	4.4	169–171
Holley	.941–.943	190–191	4.0–4.5	163–175
Seeker	.936–.943	193	7.6–12	150–165
Average of ten samples by author	.941	192.1	2.9	157.2

It can be seen from Table II, that these constants range very close to those of other oils; this adds to the difficulty of the analysis.

TABLE II

The Analytical Constants of the Drying and Semi-drying Oils

Oil.	Specific Gravity.	Saponification Number.	Iodine Number.	Acid Number.
Corn	.922	191	115	1.7–20.6
Cottonseed	.922	193	108	0.0
Linseed	.934	191	187–192	.8–8.4
Menhaden (fish)	.930	190	139–173	3–11.6
Soya bean	.923	188.2	130.7	1.9
Perilla	.934	193.8	194	1.62
Chinese wood	.941	191	150–170	4.4

The specific gravity of Chinese wood oil is higher than that of most oils and any sample below .940 should be regarded with suspicion. The iodine value is between 150-170. Dr. A. C. Chapman claims to have used the Wijs method with success. The Hanus method gives abnormally high results. The Hübl method is the one recommended for this oil and is the one the author has found most convenient, using a six hour absorption.

The acid number is low and a remarkable fact is that when this oil is heated with rosin, its acid number becomes smaller. Thus a pure Chinese wood oil with an acid value of 11.8, when heated to 392° F. with rosin, reduced its acid number to 10.7, when heated to 472° F. its acid value was only 7.

The saponification number of this oil would show the presence of mineral oil or any other oil of low saponification number.

Dr. McIlhiney has proposed a method of examination based upon the insolubility of the iodine substitution compounds formed when the oil is acted upon by iodine in acetic acid or chloroform solution. The value of this scheme is yet to be determined.

Wood oil dries to a hard film with a "crinkly" surface and at the same time gains 2 to 3 per cent in weight. Comparison with a sample of known purity will aid in the detection of adulteration.

The film will not dry as rapidly if not pure and will not be as firm. If there is much foreign material, a considerable difference in appearance can be noted.

This oil is a very profitable subject for chemical research and its industrial applications are innumerable. The chemist's efforts have given the oil its present importance and to him its future possibilities will be revealed. As the uses of the oil are multiplied, the more necessary are accurate methods for its analysis.

ENGINEERING EDUCATION TO-DAY IN AMERICA AND THE PLACE OF THE POLYTECHNIC AMONG COLLEGES OF ENGINEERING.*

WILLIAM D. ENNIS.

At a moment when the whole country preaches industrial efficiency and conservation of materials, the production of engineers who must in practice apply the new doctrines tends to decrease. Our technical schools reached a high-water mark of registration three or four years since. A shortage of technical men is imminent. It will be felt at once, and more seriously ten years hence than now. It is in fact felt now. In the current (March, 1913) number of the Bulletin of the Society for the Promotion of Engineering Education, there is printed by the General Electric Company a displayed page advertisement calling for technical graduates. The public scarcely realizes how utterly it depends upon the work of engineers. There are, according to the United States Census, about 210.000 engineers in the United States; an average of only one to the factory. The schools graduate less than 4000 engineers annually. We think of the Panama Canal as a great undertaking, of the Ohio floods as involving disastrous loss; but from the engineering-construction point of view these are of magnitude only commensurate with various routine works. Our annual fire loss; our municipal water supply; our subways; our railway maintenance expenses; the coal burned in our power plants —any of these means as much work for engineers as a Panama canal. There are only enough engineers in this country to serve as samples. More are needed and more will be used.

The engineering profession promises much to the young man who enters it to-day with a reasonable degree of aptitude and purpose. It promises more than it did twenty years ago when the usual monthly salary of a new graduate was $40. During the past four years the corresponding average for graduates of the Polytechnic Institute of Brooklyn (162 out of 196 reporting) has been $89.20. Engineering is unique among the liberal professions: it gives a living income from the start.

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* Abstract of an address given at the Polytechnic Institute, March 13, 1913.

There are a few people still who do not realize that engineering has become a liberal profession. It is commonly asserted that the engineer's prominence is purely professional and that he fails to attain public recognition. Yet in Who's Who in America (1908-09) there were 558 names from among the 10,000 members of national engineering societies. By this standard, from the general public, 1/50 of one per cent of individuals attain distinction; from the engineers, 5½ per cent.

The earnings of the young graduate are of less importance than his ultimate earning capacity. Confirmatory estimates to illustrate this latter point have been often given. An engineering college, not large or widely known, shows an average salary of $1600 within five years, $1900 in seven years, and $2250 in eight years after graduation. Prof. F. de R. Furman, writing in the Proceedings of the Society for the Promotion of Engineering Education, Vol. XVI, digests the records of the entire graduate body of a school having had an existence of 37 years. He finds that 50 per cent of graduates are "successful" within five years, 97 per cent ultimately. More than half the graduates of 20 years' standing have income independent of salary. More than half cease (within 10 years) to hold the positions of technical specialists. They become owners and chief executives or administrative heads of engineering departments. The percentage of failures as ascertained by any method of computation is practically negligible.

Fitness for the work of engineering implies technical school training. Of 98 admittedly eminent electrical engineers, 90 are college bred. The American Institute of Chemical Engineers has 183 members. All but 2 per cent attended college. To be an engineer nowadays means to be a college-trained engineer. A college of engineering is a very different thing from an industrial school. It requires high-school graduation as a condition of admission. Its course is of four years' duration. It grants baccalaureate degrees under State sanction. It may be defined as a "college" under the rules of the Carnegie Foundation for the Advancement of Teaching. This last is a positive but not a negative test. There are 70-odd "admitted" Carnegie Institutions in the country, only three in Greater New York, of which the Polytechnic is one. The Carnegie "admitted" list is a roll of honor. Listing in this class implies conformity with certain standards of size, endowment, entrance requirements and general character and efficiency of educational work.

The place of the Polytechnic among colleges of engineering may be fixed by the following considerations:

The demand for its graduates exceeds the supply. They fill the standard sorts of engineering positions and are to be found from Georgia and Tennessee to Colorado and the Canadian Northwest, from Manila to Panama.

It shows a healthy growth. To illustrate this point the registration for the course in Mechanical Engineering has about tripled in the past six years.

The entrance requirements are high, including 13 prescribed plus 2 elective "counts". The standard recommended for technical colleges by the Committee on Entrance Requirements of the Society for the Promotion of Engineering Education is 7 or 8 prescribed counts, to which 6 or 7 electives are added under the rules of the Carnegie Foundation for the Advancement of Teaching. Its courses of study in civil, electrical, and mechanical engineering and in chemisty and chemical engineering are standard courses.

The students come from all over the country and from other countries. Less than two-thirds are Brooklyn boys. The Polytechnic is in no especial sense a local institution.

The calibre of its faculty is high, as evidenced by its large expenditure for instruction; and its number of instructors is ample, in relation to its number of students. The following table taken from Bulletin No. 2, May, 1908, of the Carnegie Foundation for the Advancement of Teaching shows this:

Institution.	Number of Students.	Annual Cost of Instruction (Salaries).	Annual Cost for Instructional Salaries per Student.	Students per Instructor.
Rose Polytechnic	229	$31,600	$138	9.9
Rensselaer	485	58,721	121	16.8
Case	440	60,205	137	11.0
Worcester Polytechnic	465	61,107	132	10.1
Stevens Institute	429	69,000	161	10.2
Pennsylvania State	784	97,190	124	9.6
Lehigh	674	107,000	159	11.8
Brown	924	114,630	124	11.4
Purdue	1605	128,920	80	13.4
Syracuse	1807	180,000	100	20.3
Cornell	2917	510,931	175	10.3
Polytechnic Institute of B'klyn.	250	43,150	173	6.2

There are 33 men on the instructional staff of its engineering departments alone. It should be remembered that this item of expense is only about half the total expense of operating an engineering college, and that in most institutions the student pays only about half the actual cost of his education.

Nor is it a small institution. In 1910 it granted 53 degrees. The average number of degrees granted in the 97 colleges of engineering was under 40. Of these colleges, 74 granted fewer than 50 degrees; 23 more than 50.

The Polytechnic is fortunate in its faculty. The names of six of its professors are listed in American Men of Science (second edition). Two of these names are starred as being among those of the first thousand men of science in the United States. An unusually large proportion of the members of the Polytechnic staff hold the doctor's degree in philosophy or science. Members of its faculty have been filling or now fill the positions of President, Vice-President, Secretary, Manager, Honorary Chairman, or Director of national societies like the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the American Institute of Chemical Engineers, and the Society for the Promotion of Engineering Education. Twelve of the members of its instructing staff are the authors of 28 college text books. There have been 224 adoptions of these books in 119 schools of engineering: Practically every technical school in the country uses from one to four Polytechnic books.

The student at the Polytechnic Institute of Brooklyn has especial opportunities for contributing to his own support. Located closer than any other institution of higher education to the center of a 5,000,000 population, and directly accessible from almost all points in Greater New York, the Institute keeps its students in close touch with what is going on in engineering in the country's largest engineering city. In the Department of Mechanical Engineering, 58 per cent of its undergraduates found remunerative employment last summer. Among the seniors of the same department, 83 per cent earned an average of $370 during three years of the course. The annual earnings of 33 per cent of the seniors averaged $185. Scholarships are held by 13½ per cent of all Polytechnic undergraduate students.

The student of engineering, and particularly the student of engineering at the Polytechnic Institute of Brooklyn, is facing a particularly attractive future. In his profession failures are almost unknown. Earnings are high from the start. There is no long period of training at nominal income following the college degree. Income increases rapidly and continues to increase for more than twenty years after graduation. The earnings of engineers are seldom spectacular, but the average is high and the variation from this average is not great. Most engineers ultimately derive income additional to salary. The present production of engineers only about half equals the present demand, and the demand is steadily increasing.

The Polytechnic maintains standard four-year college courses in engineering, based upon entrance requirements even more rigid than those accepted as standard. It is an "admitted" institution of the Carnegie Foundation, granting engineering degrees under the authority of the University of the State of New York. Its annual expenditure for instruction, and the number of instructors engaged, are relatively high. It is not a small school, not a moribund school, not a local school, not an industrial school. Its graduates are in demand all over the world. Positions are available at the present moment, which we have no men to fill. The faculty ranks high by scientific, engineering, professional or educational standards. Its students are encouraged and assisted in the effort to make the most and best of themselves. Polytechnic people believe in the Polytechnic as they believe in engineering.

A RÉSUMÉ OF THE LECTURES OF SIR WILLIAM RAMSAY.*

HENRY W. SHEFF.

The series of three lectures delivered by Sir William Ramsay under the auspices of the Brooklyn Institute and the Polytechnic Institute can be, taken as a whole, considered a treatise on the history of the atmosphere. The first lecture was a review of the work of the early scientists on the gases of the air; the others an account of the speaker's own researches in discovering the rare gases present in the air.

The early part of Sir William Ramsay's talk referred us to the phlogiston period in the history of chemistry. Boyle, one of the greatest men of this period, was born in 1626 and received a good education. He could fluently write, besides his mother tongue (Irish) French, Latin, and English. Not purely scientific, Boyle showed a theological aptitude by translating the Bible into Irish. His book, "Chemista Scepticusa," gave to the world the definition of an element. He was the first to clearly state that a chemical compound resulted "from a combination of two constituents, and that it possesses properties totally different from those of either of its two constituents alone." Boyle showed that the air had elasticity or "spring" and established the law that "the volume of a gas varies inversely with the pressure."

Black, a Scotch physician, was the first to suggest balloons of hydrogen gas, and was the discoverer of latent heat. He also was the discoverer of carbon dioxide. This he found by noticing a loss in weight when magnesium carbonate was heated. He separated the gas evolved and because of the fact that it was held by caustic alkalies, lime, etc., called it fixed air. Rutherford, one of his pupils, in 1772 isolated nitrogen by the absorption in lime of the carbon dioxide produced by combustion or respiration in a limited volume of air, showing that some element which did not support combustion itself was an ingredient of the atmosphere.

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* Delivered at the Polytechnic Institute Oct. 22, 29, and Nov. 5, 1912.

Mayow, born 1643, stated that air was composed of more than one substance, and showed that a mouse died more quickly in the upper part of a sealed jar. He made an assumption that the air contained a substance capable of supporting combustion which also sustained respiration. He was, however, unable to isolate this substance before he died. It was not until a century later that Priestley and Scheele, working independently, succeeded in separating this substance. In 1774 Priestley obtained oxygen by heating red oxide of mercury, while Scheele obtained the same gas by utilizing other oxides. The apparatus used by these men, as well as that in use to-day, are gradual developments of the apparatus of Hales, a clergyman and a great student of botany. He endeavored to determine the exact properties, weight, measure and number of all things. A few of the things he worked on are hog's blood, camphor, sugar, coal, earth, and tartar. He didn't examine any gases formed but contented himself with just measuring their volumes. He found that when he heated plants an "air" was given off. (The word gas had not yet been introduced by von Helmont and all gases were called air.)

Stahl, a pupil of von Helmont, introduced the phlogiston theory. This theory rests upon the hypothesis that combustible substances contain a common ingredient, namely phlogiston, which is given up on heating. The greater the ease or violence of combustion, the more phlogiston a substance contained. Stahl states that when a metallic calx is heated with coal the metal is revived by the addition of phlogiston from the coal. That is to say that the products of combustion, as we now understand them, were simple products (metals deprived of phlogiston), while the pure metal was a phlogiston compound. Lavoisier, a wealthy and well-educated Frenchman, gave an explanation to the work of Black, Priestley, and Scheele and showed the fallacy of Stahl's theory by proving that the product of combustion was a combination of oxygen with the substance used.

and that the obtaining of pure metal was possible by the extraction of oxygen from the calx. He was a pioneer in the use of the balance in this work and proved that hydrogen had weight.

Cavendish, called the founder of pneumatic chemistry, was born in 1731. To him we are indebted for the proof that water consists of hydrogen and oxygen, and that the air is composed of nitrogen and oxygen in definite and constant proportions which he determined by analysis to be oxygen 79.16 per cent and nitrogen 20.84 per cent. In showing the composition of the air, Cavendish made use of a U tube filled with air through which was passed an electric spark. He determined that 1/720 part of the whole air will not combine with oxygen. His determination of the density of the earth has not been improved upon.

It was about one century later, 1894, that Lord Rayleigh was working upon densities of gases. He found that nitrogen from the air weighed more than the nitrogen obtained from ammonia or nitric acid. Sir William Ramsay, at the reading of Rayleigh's findings, thought of the possibility of some new gases (compounds or elements). When he mentioned this to his friends he was laughed at and told that this difference was no doubt due to carelessness in the weighing of the different samples of nitrogen by Gordon, Rayleigh's assistant. Ramsay, however, thought that nitrogen from the air contained some heavier gases. He started experimenting, keeping in communication with Rayleigh.

Ramsay passed and repassed air through this apparatus and finally found a gas whose density was 15 times that of hydrogen. As nitrogen was only 14 times heavier than hydrogen, this gas, which was clearly nitrogen and something else, was again put through a suitable apparatus until he finally obtained a gas 18 times heavier than hydrogen. This gas was then sparked in an apparatus similar to the U tube of Cavendish. The result, a gas 20 times heavier than hydrogen, showed that there was a gas or gases present in the air of unknown character.

Ramsay used two methods in separating his samples of nitrogen from the air. In one method the air was passed through pipe-stems. Nitrogen and oxygen diffuse through more quickly than the other gases. After diffusion a gas was obtained other than nitrogen and oxygen. In the other method, the phenomena that gases dissolve to some extent in water, and nitrogen is more soluble than oxygen are applied. Air was shaken with water and the gases pumped out. The new gas was found to be more soluble than either nitrogen or oxygen. The new gas was called Argon (Greek, meaning idle), from the fact that it was chemically inactive.

Gases are composed of molecules, atoms or groups of molecules. These are perfectly round, perfectly elastic, and their surfaces very smooth. A billiard ball has a rough surface compared with that of each of the minute particles of the gas. It is a well-known fact that when a gas is heated it expands, and this property is used to find the specific heat of the latter. When a molecule of two atoms is heated a greater heat is necessary to produce the same effect than for a one atom molecule. When the specific heat of argon was found, the heat taken up showed that it was a single atom molecule. As hydrogen is a diatomic molecule and argon is a monatomic element, 20 times heavier, the atomic weight of the latter is equal to twice 20, or 40.

The next thing was to find the compounds of argon. This gas exhibited a property never before known—the fact that it would combine with neither oxygen nor magnesium. Here Ramsay was helped by the work of an American mineralogist, who noticed that a certain Uranium mineral gave off a gas. The spectrum of this gas showed the presence of nitrogen and also showed some new lines. Friends rebuffed him, but he communicated with Ramsay, who examined the mineral. The gas exhumed from cleavite was purified by sparking and the spectrum taken. This was found to differ from the argon spectrum. In 1868 the same lines were distinguished by use of a spectroscope in the examination of an eclipse of the sun. The new gas was called Helium (from helios, the sun). No compounds of it were found and the density was determined at twice that of hydrogen.

An earlier chemist gave an idea of the periodic system, taking as an example the octave in music. The laughter of his contemporaries caused him to stop work in this direction. But a few years later, Mendelejeff gave out the periodic arrangement of the elements. This system, as is known, is arranged according to the atomic weights of the elements. It plainly shows that there is an approximately constant difference in the atomic weights in the different columns and rows. This difference in the columns is about 16 and in rows about 3 times 16. According to the tables there should be an element between helium and argon. In searching for it, Ramsay tested the great collection of minerals in the British Museum with no results. The gases of the different mineral springs of Europe were next tested. Here there was a recurrence of the spectra of helium and argon, but no new lines. He next tested some meteorites, but of all, only one gave the lines of helium and not one gave new lines.

At this time, 1896, liquid air was comparatively rare. From a sample of this, Ramsay collected a quantity of argon which he used to find the new gas he was seeking, but was unsuccessful. He took a sample of one liter of liquid air and examined the residue after extracting the nitrogen and oxygen and found some new lines in the spectroscope. This new gas was called Neon (new). Its density was found to be 10 times that of hydrogen and the atomic weight 20. In this same spectrum he saw other new lines, which on further investigation revealed another new gas which he called Krypton, density 41, atomic weight 82. By fractionating these gases in 1898-1900 a new gas was found, which was called Xenon (rare or stranger) the density of which was found to be 66, and the atomic weight 132. Xenon was separated from neon by liquid hydrogen.

To give his audience a clearer idea of the relative amounts of rare gases in the atmosphere Ramsay said, "There is more gold in sea water than Xenon in the air."

Evidence was found of the presence of a gas heavier than xenon, but this has not yet been isolated. This gas, called Niton, is unstable, and the instability produces the electrification of the atmosphere. It was found by Becquerel that pitchblende was radio-active and therefore contained a radio-active substance. He also noticed that paper after being exposed to light retained its light in the dark. This was shown by attaching a piece of paper to a wheel which on turning would first bring the paper in the light and then in the dark. Uranium was found to possess the phenomenon of retaining its light in the dark after exposure to the light. This was proved by placing some uranium on a photographic plate after having been exposed to light for some time. Development of the plate showed the photograph of the uranium. Later it was proved that exposure of the uranium to light was unnecessary to get the same effect on the photographic plate, clearly demonstrating that rays emanated from some substance contained in the uranium. Mme. Curié, separating pitchblende, found bismuth, which possessed radio-activity due to the presence of some other substance. By repeated crystallizing and recrystallizing the more radio-active part, she at last obtained an extremely radio-active substance which was found to be a salt of radium.

Radium is an unstable substance breaking up into uranium, ionium, radium, and radium emanations. Sir William Ramsay and his assistant Dr. Soddy, who were accustomed to working with very small quantities of gases, examined the gases of radium which were collected in a vacuum over mercury. The spectrum of this gas was found to coincide with that of helium and radium was found to break up into helium and radium emanation, which again breaks up into helium and radium No. 2. The spectrum of radium emanation was found to be similar to that of helium and the gas was found to be a true gas. The liquid of radium emanation produces a violet shine on glass and on solidification it produces an effect like an arc light. The solid is opaque and the liquid transparent. Wishing to weigh this gas, of which they had but 1/10000 cubic centimeter, the scientists were forced to construct a new balance. After 10 years they succeeded in making one with silver wire arms and a knife edge ground so smooth that it appeared smooth under a microscope. The scale was made of silica fibers and a small bulb in which the gas was placed served in the place of a pan. Since no weight could be made small enough to weigh this minute quantity of gas, the weighings were accomplished by extracting air from the balance case and measuring the pressure. The balance was later improved by replacing the silica fibres by quartz fibres.

By use of the above balance the atomic weight of niton was found to be 223. Niton decomposes after 3 months into helium and for this reason was not found in the residue of xenon. This period of life was determined by weighing a sample of the gas at intervals until the weighings were constant. Niton continually gives out helium but the latter can only be detected by its electric properties as exhibited by means of an electroscope.

THE PREDETERMINATION OF THE VOLTAGE—REGULATION OF ALTERNATORS.

SAMPSON K. BARRETT.

A practically constant voltage is very desirable for lighting service, since the quality and quantity of light emitted by the most recent types of incandescent lamps, as well as the useful life of the same, change greatly with a small variation in the impressed electromotive force. To maintain a fairly constant voltage even with automatic regulators and especially with manually operated devices, the generator must have a good inherent regulation, less than 6 per cent being commonly specified. Since good inherent regulation means increased cost, a regulation of only 8 per cent or greater is frequently required of alternators for power service.

The inherent regulation of an alternator is the ratio of the maximum difference of terminal voltage from the rated-load value, occurring within the range from rated load to open circuit, to the rated-load terminal voltage, the speed and field current remaining constant. As the maximum deviation during this range generally occurs at rated load, the regulation is frequently expressed in the form of an equation:

$$\text{Regulation in per cent} = \frac{\text{No-load voltage} - \text{Full-load voltage}}{\text{Full-load voltage}} \times 100$$

With small machines the regulation is most easily determined from load tests. With large alternators the large amount of power required for a load test may necessitate the predetermination of the regulation from either design constants or test data simulating operating conditions but requiring little power.

Primarily, three causes operating simultaneously produce change in terminal voltage with variation in load. In order of relative influence on voltage drop they are: armature reaction, armature reactance, armature resistance.

Armature reaction may result in a cross-magnetization, a magnetization, or a demagnetization effect. When the current in an armature conductor is a maximum and lags 90° behind the induced electromotive force, demagnetization results, as the magnetomotive force due to the armature current tends to produce a flux in the paths indicated in Fig. 1, and therefore opposes the magnetomotive force of the field coils. Similarly, if the armature current leads the electromotive force by 90°, magnetization results, since the magnetomotive force due to the armature current assists that of the field winding; that is, capacity loads produce a compounding effect on the field.

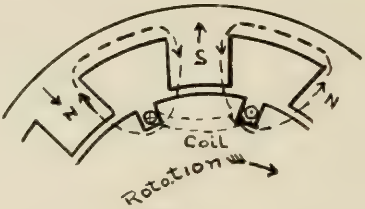

Fig. 1.

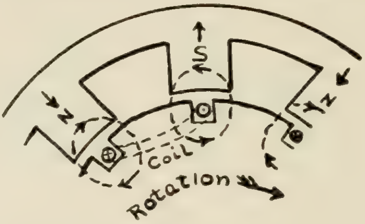

Fig. 2.

Fig. 2 shows that when the armature current is a maximum and in phase with the induced electromotive force cross-magnetization results. Evidently, with the current lagging less than 90°, the armature magnetomotive force results in both demagnetization and cross-magnetization, and with a current leading by less than 90° a magnetization and a cross-magnetization effect is produced.

Since distributed windings are generally used and the armature coils have self-inductance, the current and voltage in different coils have various phase relations. Hence, both cross-magnetization and demagnetization effects are simultaneously produced and in varying amounts dependent upon the position of the armature coils and the phase and magnitude of the armature current at any instant. In single-phase revolving-armature alternators the armature magnetomotive force is pulsating at any given point of the field structure while in polyphase alternators of the revolving armature type the armature magnetomotive force is constant in value and fixed in space for a steady balanced load. In polyphase alternators of the revolving field type the armature magnetomotive force varies in such a manner that its tendency is to produce a synchronously rotating magnetic field.

The armature reactance, like any inductive reactance, is equal to 2π times the frequency times the self-induction of the armature. The inductance of the armature varies widely with the relative position of the armature conductors and the poles. The counter electromotive force produced by the leakage flux, associated with the alternating armature current, cutting the imbedded armature conductors and the end connections is therefore variable. This reactance voltage drop may be from 3 to 6 per cent of the rated voltage.

The armature resistance drop has a small effect for loads of unity power factor and is negligible at zero power factor.

Since a sinusoidal distribution of flux due to the armature magnetomotive force would necessitate field magnets uniformly surrounding the armature instead of polar projections, and the reactance voltage drop is not a harmonic function, no diagram using plane vectors can exactly represent all the quantities, and hence it is impossible to formulate any simple and exact method for predetermining the voltage drop in an alternator.

If all the above factors affecting voltage drop are assumed to vary harmonically with time and a further assumption of constant reluctance is made, we may represent the magnetomotive and electromotive forces operative in an alternator on non-inductive load as in Fig. 3. The field excitation produces a magnetomotive force M_f which is reduced by the armature magnetomotive force M_a, leaving an effective magnetomotive force M, which induces an electromotive force E_0 in quadrature. This induced electromotive force is reduced by a reactance voltage drop IX and a resistance voltage drop IR, leaving a terminal voltage E with a non-inductive load of I amperes. The cross-magnetizing and demagnetizing effects are respectively represented by the vectors $M_a \cos B$ and $M_a \sin B$. This analysis shows that the voltage drop is caused by a lost magnetomotive force $-M_a$ and a lost electromotive force $-IZ$. There are in general use two methods of predetermining the voltage regulation of an alternator: the electromotive force method and the magnetomotive force method. The former method assumes that the total voltage drop in an alternator is due to lost electromotive force only, while the latter method assumes that it is wholly due to lost magnetomotive force. All other methods are essentially either a combination of these two or a modification of one.

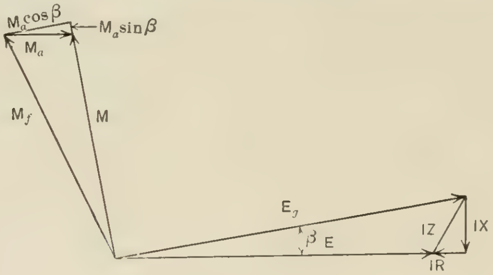

FIG. 3.

The electromotive force method, also called the E.M.F. method, gives the machine a poorer regulation than the actual, and has therefore been called the "pessimistic" limit. The magnetomotive force method, also called the M.M.F. method, gives a better regulation than the true and hence is called the "optimistic" limit. Both methods would give the same result if the no-load saturation curve were a straight line so that magnetomotive forces would be proportional to electromotive forces.

To compute the regulation of an alternator by either of these methods necessitates three tests requiring but little power: the measurement of the hot resistance of the armature, the determination of the no-load saturation curve and of the short-circuit characteristic.

The hot armature resistance may be measured by the fall-of-potential method directly after a heat run, or the armature resistance may be measured at room temperature and its value at 75° C. then computed and used in subsequent calculations as the hot armature resistance. The armature resistance is generally measured between slip rings in the revolving—armature type or between terminals in a revolving-field alternator. In polyphase alternators the average resistance between slip rings or terminals is used.

The no-load saturation curve shows the relation between terminal volts and field exciting amperes with the armature on open circuit, the field being separately excited and the speed being maintained constant at its rated value. It is customary to use the ascending curve obtained by continuously increasing the field current. For polyphase machines the average of the terminal volts for each phase is used as the ordinate of the curve.

The short-circuit characteristic shows the relation between the field current and the short-circuit current, the armature being short circuited through short heavy conductors and an ammeter of low impedance. It is, therefore, preferable to use an instrument whose range is two or three times the rated full-load current. It is essential that the short circuit be made with weak field since with normal field excitation the sudden or initial short-circuit current may be 7 to 12 times the normal full-load current while the steady or normal short-circuit current is only 2.5 to 4 times the rated current in machines of good inherent regulation. Turbo-generators may have an initial short-circuit current of from 30 to 40 times the full-load current. The initial short-circuit current is limited by the armature reactance but the additional effect of armature reaction reduces this short-circuit current to the normal or steady value. Due to the perponderating influence of armature reaction the effective field strength that produces rated full-load current through the armature is reduced to about one per cent of its normal value at full load. For any point below the knee of the no-load saturation curve the ratio of the terminal volts on open circuit to the short-circuit amperes produced by the same field excitation is defined as the synchronous impedance, which is a fictitious quantity including both true armature impedance and armature reaction and is generally assumed constant over the operating range of the machine. Owing to the relatively small value of the armature resistance the error, due to assuming the synchronous impedance of the armature equal to the synchronous reactance, is negligible. In polyphase alternators each phase is short circuited through an ammeter and the average short-circuit current per armature phase is used as ordinates for the short-circuit curve. In a three-phase alternator it is desirable to connect the three ammeters in Y for a Y-connected armature and in Δ for a Δ-connection of armature, so that readings of instruments are amperes per phase of armature. Since a high synchronous impedance means protection for the machine on short circuit it is desirable to specify the impedance ratio which is defined as the ratio in per cent of the synchronous impedance drop at full-load current to the terminal voltage at full-load.

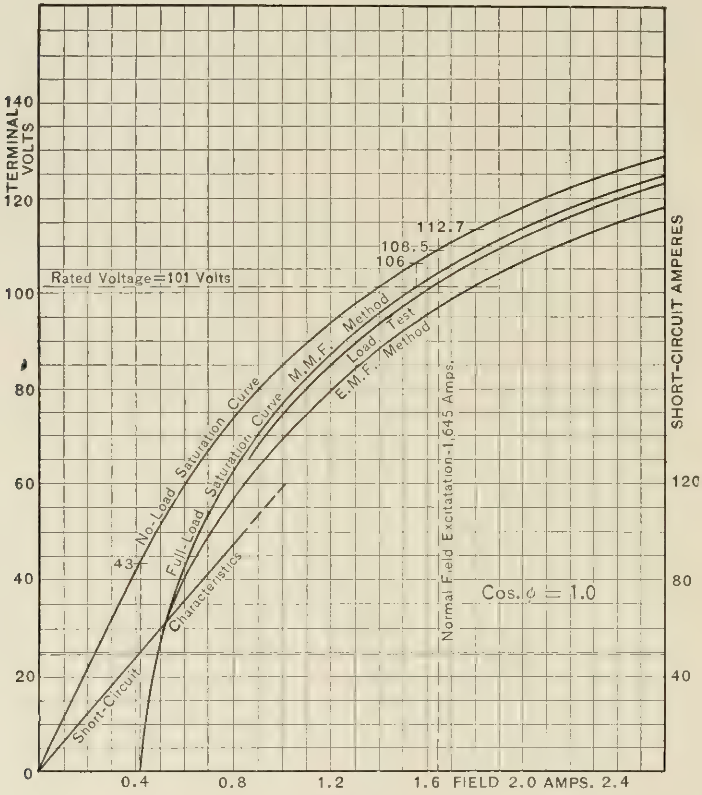

Fig. 4.

Tests of a General Electric Company laboratory unit, whose rating as a single-phase alternator is: 5 kilowatts, 49.5 amperes, 101 volts at 1800 revolutions per minute, gave a hot armature resistance of 0.064 ohms, and the no-load saturation curve and the short-circuit characteristic of Fig. 4.

For a non-inductive load, the electromotive forces of an alternator may be represented as in Fig. 5 where E represents the rated terminal voltage at full load, E_g the total generated voltage and IR, IZ, and IX represent respectively the resistance, the impedance, and the reactance voltage drops. It is evident from Fig. 5 that for non-inductive loads:

$$E_g=\sqrt{(E+IR)^2+(IX)^2}.$$

Hence,

$$\text{Regulation in per cent}=\frac{E_g-E}{E}\times 100;$$

$$IR=49.5\times 0.064=3.2 \text{ volts}.$$

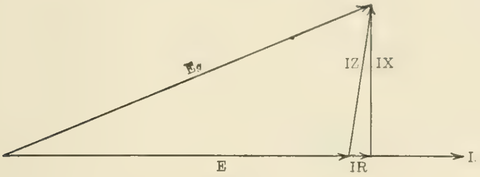

FIG. 5.

Reference to Fig. 4 shows that a field excitation of 0.425 amperes is required to produce full-load current on short-circuit and that the same field amperes induce a terminal voltage of 43 volts on open circuit.

Hence, if Z and X are respectively the synchronous impedance and reactance,

$$Z=\frac{43}{49.5}=0.868 \text{ ohms}.$$

$$X=\sqrt{Z^2-R^2}$$

$$=\sqrt{\overline{0.868}^2-\overline{0.064}^2}=0.8656 \text{ ohms};$$

$$IX=42.85 \text{ volts}.$$

That is, IZ differs from IX by less than 0.3 of one per cent and therefore considering the accuracy with which IZ is determined and the necessary assumptions concerning the synchronous reactance it is reasonable to use IZ for IX.

$$E_g=\sqrt{(E+IR)^2+(IX)^2}$$

$$=\sqrt{(101+3.2)^2+(43)^2}=112.7 \text{ volts}.$$

$$\text{Regulation}=\frac{E_g-E}{E}\times 100$$

$$=\frac{112.7-101}{101}\times 100=11.58 \text{ per cent}.$$

As magnetomotive forces are directly proportional to the exciting amperes the magnetomotive force relations in an alternator for non-inductive load may be represented by Fig. 6 where $I_{f'}$ represents the field excitation corresponding to $(E+IR)$ volts and I_{fx} that corresponding to the synchronous reactance drop and I_{fg} the field amperes producing the open circuit voltage E_g.

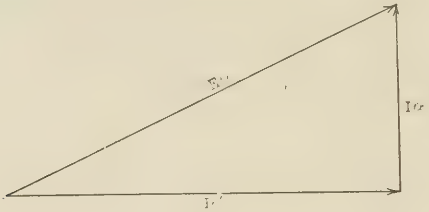

FIG. 6.

From no-load saturation curve,

$I_{f'}=1.5$ amperes for $(E+IR)=104.2$ volts;

$I_{fx}=0.425$ amperes for $IX=43.0$ volts;

$$I_{fg}=\sqrt{(I_f')^2+(I_{fx})^2}$$

$$=\sqrt{1.5^2+0.425^2}=1.56 \text{ amperes.}$$

Hence $E_g=106$ volts.

Therefore, by the M.M.F. or A.I.E.E. method:

$$\text{Regulation}=\frac{106-101}{101}\times 100=4.95 \text{ per cent.}$$

Averaging the results of the two methods:

$$\text{Regulation}=\frac{11.58+4.95}{2}=8.27 \text{ per cent.}$$

The true regulation as determined from a load test is:

$$\frac{108.5-101}{101}\times 100=7.43 \text{ per cent.}$$

For inductive load, Fig. 7 shows that

$$E_g=\sqrt{(E\cos\phi+IR)^2+(E\sin\phi+IX)^2}.$$

Hence, for a power factor of 80 per cent,

$$E_g=\sqrt{(101\times 0.8+3.2)^2+(101\times 0.6+43)^2}=133.4.$$

$$\text{Regulation}\quad=\frac{133.4-101}{101}\times 100=32.1 \text{ per cent.}$$

For inductive loads, according to the general interpretation of the M.M.F. method, field currents corresponding to the terminal voltage, armature resistance drop and armature reactance drop are added vectorially and the voltage on the no-load saturation curve corresponding to this resultant field current is taken as the open-circuit pressure. That is:

$$I_{fg}=\sqrt{(I_f \cos \phi+I_{fR})^2+(I_f \sin \phi+I_{fx})^2}$$

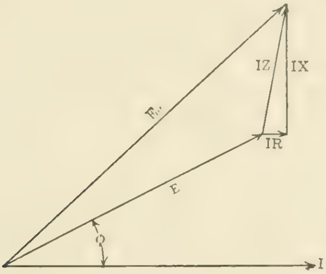

FIG. 7.

Some authors, notably Franklin and Esty, vectorially add field currents corresponding to the quadrature components of the total generated electromotive force.

For full-load current at a power factor of 80 per cent

$$I_{fg}=\sqrt{(1.41\times0.8+0.032)^2+(1.41\times0.6+0.425)^2}=1.72.$$

Hence, $E_g=110.5.$

$$\text{Regulation}=\frac{110.5-101}{101}\times100=9.4 \text{ per cent.}$$

In predetermining the regulation of polyphase generators the current per phase and the voltage per phase are more commonly used. Great care must be taken in interpreting results or erroneous conclusions are reached. Polyphase quantities, however, are frequently reduced to *equivalent single-phase* quantities because of the greater simplicity and the lesser liability to error in computations, and also because the results are in a more suitable form for comparative purposes.

The equivalent single-phase current in any balanced polyphase system is the current which, multiplied by the line voltage and the power factor, gives the true total power. Hence, since for a three-phase alternator

$$P=\sqrt{3}EI\cos\phi,$$

$$\sqrt{3}EI\cos\phi=EI_{eq}\cos\phi,$$

or

$$I_{eq}=\sqrt{3}I;$$

where I_{eq} is the equivalent single-phase current and I is the line current.

The equivalent single-phase resistance is that resistance which, multiplied by the square of the equivalent single-phase current gives the total copper loss. In a three-phase alternator with a Y-connected armature the total copper loss is equal to $3I^2r$, where r represents the armature resistance per phase.

Hence,

$$3I^2r=I_{eq}^2R_{eq};$$

$$3\frac{I_{eq}^2}{3}r=I_{eq}^2R_{eq};$$

$$R_{eq}=r.$$

If R represent the resistance between terminals or slip rings as measured by the fall-of-potential method then, $r=\frac{R}{2}$,

or

$$R_{eq}=\frac{R}{2}.$$

Similarly for a Δ-connected armature the total copper loss is $3\left(\frac{I}{\sqrt{3}}\right)^2r$.

Hence

$$I^2r=I_{eq}^2R_{eq};$$

$$\frac{I^2_{eq}r}{3}=I^2_{eq}R_{eq};$$

$$R_{eq}=\frac{r}{3}.$$

But,

$$R=\frac{2}{3}r.$$

Whence, $R_{eq}=\frac{R}{2}$, that is, the equivalent single-phase resistance equals one-half of the armature resistance between the line terminals of the armature.

The total copper loss in a Y-connected armature may also be expressed as

$$P_c=3Iz\times I\times\cos\theta=3I^2z\cos\theta$$

where $\cos\theta=\frac{r}{z}$, and z represents the armature impedance per phase.

Hence,
$$3I^2z\cos\theta=I_{eq}^2Z_{eq}\cos\theta;$$

$$3\frac{I_{eq}^2}{3}z\cos\theta=I_{eq}^2Z_{eq}\cos\theta;$$

$$Z_{eq}=z.$$

In a Δ-connected armature $P_c=3\left(\frac{I}{\sqrt{3}}\right)^2z\cos\theta;$

$$I^2z\cos\theta=I_{eq}^2Z_{eq}\cos\theta;$$

$$Z_{eq}=\frac{z}{3}.$$

If Z represents the impedance between armature terminals, since it is measured by a voltmeter-ammeter method in a similar manner to the resistance between armature terminals, it is evident that $Z_{eq}=\frac{Z}{2}$. That is, the equivalent single-phase impedance is one-half of the impedance between the line terminals of the armature.

By substituting in the foregoing equations

$$z=\sqrt{r^2+x^2};$$

$$Z_{eq}=\sqrt{R_{eq}^2+X_{eq}^2};$$

and

$$R_{eq}=\frac{R}{2},$$

it may be shown that $X_{eq}=\frac{X}{2}$, where x and X represent respectively the armature reactance per phase and the armature reactance between line terminals.

The following tests were performed on a General Electric Company laboratory unit which is rated as a three-phase generator at 6 kilowatts, 42.5 amperes, 81.5 volts, 60 cycles. The average hot resistance between armature terminals is 0.0578 ohms and the no-load saturation curve and the short-circuit characteristic are represented respectively by curves I and II in Fig. 8.

The equivalent single-phase full-load current is 42.5×1.73 or 73.5 amperes. The other equivalent single-phase quantities are:

$$R_{eq}=\frac{R}{2}=\frac{0.0578}{2}=0.0285,$$

$$Z_{eq}=\frac{Z}{2}=\frac{0.713}{2}=0.356 \text{ ohms.}$$

where $Z=\frac{\text{line volts}}{\text{line amperes}}=\frac{30.3}{42.5}=0.713$ ohms.

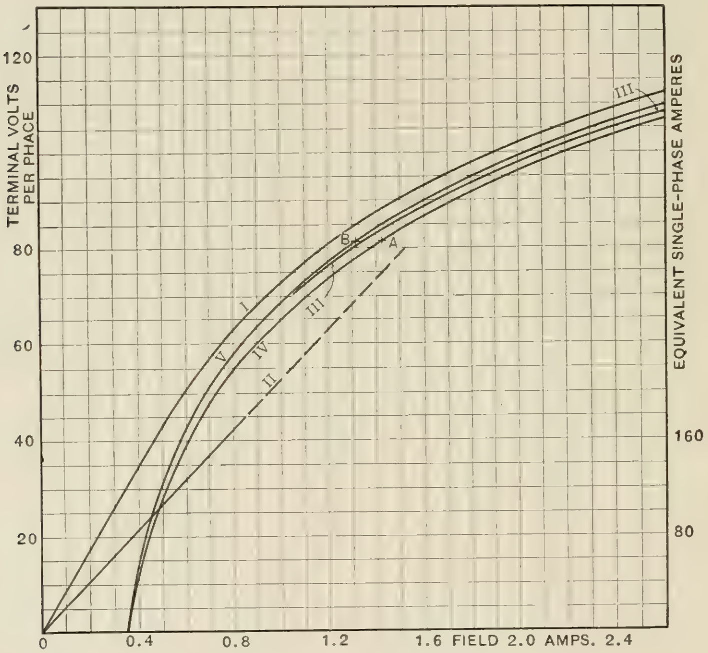

FIG. 8.

Hence, at full-load the equivalent single-phase resistance and reactance voltage drops are respectively 2.1 and 26.2 volts.

Therefore, by the E.M.F. method for non-inductive load:

$$E_g=\sqrt{\overline{83.6}^2+\overline{26.2}^2}=87.7.$$

This locates point A on curve IV, Fig. 8. Other points may be similarly derived and curve IV through such points is the full-load saturation curve for unity power-factor load as predetermined by the E.M.F. method.

$$\text{Regulation}=\frac{87.7-81.5}{81.5}\times 100=7.6 \text{ per cent.}$$

By the Institute or M.M.F. method:

$$I_{fg}=\sqrt{\overline{1.3}^2+\overline{0.303}^2}=1.334 \text{ amperes;}$$

$$E_g=84.8 \text{ volts.}$$

This locates point B on curve V, Fig. 8. Other points may be similarly determined and the resulting curve is the full-load saturation curve for unity power-factor load as predetermined by the M.M.F. method.

$$\text{Regulation}=\frac{84.8-81.5}{81.5}\times 100=4.05 \text{ per cent.}$$

The average of the two results is 5.83 per cent.

Curve III, Fig. 8, is the full-load saturation curve for non-inductive load as derived by loading. From this curve the true voltage regulation is found to be

$$\frac{86-81.5}{81.5}\times 100=5.52 \text{ per cent.}$$

Curve III also shows that for this machine the M.M.F. method gives the most correct result when it is operated below saturation. This holds true in most commercial machines operated near or below the knee of the magnetization curve.

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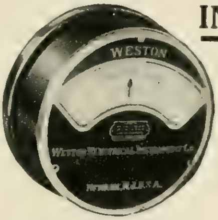

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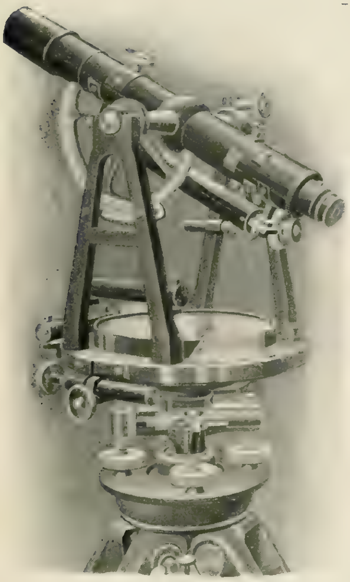

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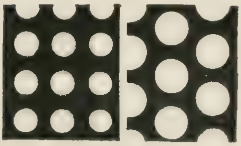

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